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United States. Board of Consulting Engineers on Panama Canal.

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REPORT

OF THE

BOARD OF CONSULTING ENGINEERS

FOR THE

PANAMA CANAL

5808

WASHINGTON
GOVERNMENT PRINTING OFFICE
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E. Quellennec, Ingénieur en Chef des Ponts et Chaussées; Ingénieur Conseil de la Cie. du Canal de Suez, France.

J. W. Welcker, Hoofdingenieur-Directeur van den Ryks-Waterstaat, The Netherlands.

John C. Oakes, Captain, Corps of Engineers, General Staff, U. S. Army, *Secretary.*

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WASHINGTON, D. C., *January 10, 1906.*

The ISTHMIAN CANAL COMMISSION.

GENTLEMEN: The Board of Consulting Engineers for the Panama Canal, having completed the consideration of the question submitted to it in pursuance of the order of the President dated June 24, 1905, has the honor to submit its report.

The President's order is as follows:

EXECUTIVE ORDER.

It is hereby ordered that a Board of Consulting Engineers, consisting of—

General George W. Davis,
Mr. Alfred Noble,
Mr. William Barclay Parsons,
Mr. William H. Burr,
General Henry L. Abbot,
Mr. Frederic P. Stearns,
Mr. Joseph Ripley,
Mr. Herman Schussler,
Mr. Isham Randolph,
Mr. Wm. Henry Hunter, nominated by the British Government,
Herr Eugen Tincauzer, nominated by the German Government,
M. Guérard, nominated by the French Government,
M. Quellennec, consulting engineer, Suez Canal, and one engineer to be designated by the Government of the Netherlands,

shall convene in the City of Washington, at the rooms of the Isthmian Canal Commission, on the 1st day of September, 1905, for the purpose of considering the various plans proposed to and by the Isthmian Canal Commission for the construction of a canal across the Isthmus of Panama between Cristobal and La Boca; and that the deliberations of the Board of Consulting Engineers shall continue as long as they may deem it necessary and wise before they make their report to the Commission.

The Isthmian Canal Commission is directed to have all the proposed plans in such detailed form, with maps, surveys, and other documents sufficient to enable the Consulting Engineers to consider and decide the questions presented to them. Should it be deemed necessary by the members of the Consulting Board, they may visit the Isthmus before making their final report. If there is a difference of opinion between the members of the Consulting Board, minority reports are requested.

General George W. Davis is hereby designated as chairman of the Board of Consulting Engineers. Instructions more detailed will be given in time to be presented to the Board when it first convenes on the 1st of September.

The chairman is charged with the duty of communicating to the other members of the Board this order and the other details that may be necessary.

THEODORE ROOSEVELT.

THE WHITE HOUSE, *June 24, 1905.*

SUMMARY OF PROCEEDINGS.

The Board met in the office of the Isthmian Canal Commission, Washington, D. C., on September 1, 1905, all the gentlemen named in the order being present with the following exceptions:

Mr. Herman Schussler, who notified the chairman of the Board that on account of previous engagements and undertakings that could not be changed he felt obliged to decline the appointment.

Mr. J. B. Berry, chief engineer, Union Pacific Railroad, who had been named by the President as a member in place of Mr. Schussler, declined the appointment on account of his responsibility to the railroad company, which required all of his time.

Prof. Jaeon Kraus, chief of waterstaat, Netherlands Government, who had been named as the representative of Holland on the Board, was shortly thereafter called to a position in the ministry of the Government, and he therefore was obliged to decline the appointment.

To fill the place thus made vacant, Mr. J. W. Welcker, chief engineer of waterstaat, was nominated by the Government of the Netherlands. Mr. Welcker sat with the Board as the Dutch member.

After organization and the reading of the order of the President, the Chairman announced that Capt. John C. Oakes, Corps of Engineers, General Staff, U. S. Army, had been detailed by the War Department to act as secretary to the Board, and he has so acted.

The Board received the following communication from the Chairman of the Isthmian Canal Commission:

ISTHMIAN CANAL COMMISSION,
Washington, D. C., September 1, 1905.

THE BOARD OF ENGINEERS ADVISORY UPON PLANS FOR THE PANAMA CANAL,
Washington, D. C.

GENTLEMEN: In accordance with the directions of the President, dated April 1, 1905, the Isthmian Canal Commission has the honor to lay before you physical data concerning the Isthmus of Panama, and to solicit your opinion as to the best plan to be followed in the completion of the Panama Canal within reasonable limits of cost and time.

As you are aware, this question has been the subject of prolonged and elaborate studies for many years by numerous able engineers. A vast amount of labor has been expended in the collection of information concerning the physics of the Isthmus, and in digesting it and formulating it into plans for the canal. The results of all these labors, both in the field and in the office, down to a recent date are given in the reports of two distinguished commissions, viz, the Comité Technique, of which the report is dated at Paris, November 16, 1898, and the American Commission of 1899–1901, of which the report is dated at Washington, November 16, 1901. A careful perusal of these reports, and examination of the maps and documents which accompany them, will afford as satisfactory a view of the entire subject, at the dates when they were written, as can now be given. They have been reprinted, each in a separate pamphlet, and in that form are now handed to you marked "Part I," and "Part II," respectively.

During the last year additional surveys and observations have been made upon the Isthmus, the results of which are laid before you. It may be stated here in general terms that the information which they furnish does not involve any radical change in the plans previously favored. Among the observations alluded to may be included the experience of the last year in excavating the Culebra cut, from which some of our engineers have drawn unwarranted conclusions as to the probable cost of the work. There is nothing in this experience to justify the belief that the unit prices used in previous estimates were too high, or that the estimate of the time required for completing the work was too liberal. Nevertheless, this experience has been used as an argument in favor of a sea-leval canal, which plan had been condemned by the two commissions mentioned above. It becomes necessary to consider once more the sea-level scheme. The principal information available for a decision as to the merits of that project has been printed in the form of a third pamphlet, which is now handed to you, marked "Part III," and in which will be found the more important results of the recent surveys.

These three pamphlets are commended to your careful consideration. With the large map, scale 1:5,000, of which a copy is also handed to you, it is hoped that a fair idea may be obtained of the conditions on the Isthmus, and of the relative merits of the three plans proposed. There are on file here many other maps, reports, and drawings, any or all of which will be placed at your disposal should there be any point which requires further elucidation.

The plan described in the first pamphlet is the one which was adopted by Congress, at least by inference, in the act approved June 28, 1902. It is the plan under which the work is now progressing, and under which all work of construction has been done since the United States acquired the property. It closely resembles the plan of the Comité Technique, described in the second pamphlet, in many essential particulars, but differs from it in the height of the Bohio dam and the important results which flow therefrom. The advantages which its authors expected to derive from this change were:

1. To take fuller advantage of the topography of the country, by which it was possible to make the Gigante spillway automatic, instead of mechanical, and adequate for the discharge of the greatest floods, with only one channel to the sea instead of two.

2. To increase the distance of lake navigation from seven to nearly thirteen miles.

3. To reduce the estimated cost of the canal by about $15,000,000.

The disadvantages of the change are the somewhat greater difficulties in constructing the higher dam and the locks of greater lift—difficulties, however, which are by no means insuperable.

A disadvantage which the two plans have in common is that the rapid developments of naval architecture make it difficult to determine the proper dimensions of the lock chambers. It is to be considered, however, that up to the present time such development has not been greatly hampered by deficient depth in the harbors of the world, and that development hereafter will have that obstruction to contend with. Moreover, it is not possible to dispense with locks entirely. Even with the sea-level canal a tide lock will be required at the Panama end.

In addition to the plans above mentioned, a pamphlet has been prepared by Mr. Lindon W. Bates, which gives in outline a sketch of a plan proposed by him, which is interesting on account of its novelty, and is, therefore, laid before you. It does not give detail enough for a close analysis, nor for estimates of cost. To obtain this, extensive additional surveys, to occupy at least a year's time, would be necessary.

A paper has been submitted to the President by Mr. P. Bunau-Varilla which explains a method by which a canal constructed at first with locks may be subsequently altered to a sea-level canal. This paper also is submitted for your consideration.

These last two documents are described in a fourth pamphlet, marked "Part IV," which is now handed to you.

It is to be noted that the law by which Congress ordered the construction of an Isthmian Canal contained the following proviso, viz:

"The President shall then, through the Isthmian Canal Commission hereinafter authorized, cause to be excavated, constructed, and completed, utilizing to that end, as far as practicable, the work heretofore done by the New Panama Canal Company, of France, and its predecessor company, a ship canal from the Caribbean Sea to the Pacific Ocean. Such canal shall be of sufficient capacity and depth as shall afford convenient passage for vessels of the largest tonnage and greatest draft now in use, and such as may be reasonably anticipated, and shall be supplied with all necessary locks and other appliances to meet the necessities of vessels passing through the same from ocean to ocean; and he shall also cause to be constructed such safe and commodious harbors at the termini of said canal and make such provisions for defense as may be necessary for the safety and protection of said canal and harbors."

The Commission expects to visit the Isthmus of Panama, sailing from New York during the last week in September, the exact date to be fixed hereafter. You are cordially invited to accompany them.

This method of presenting the subject to you, by offering several well-digested plans, has been adopted because it seemed to be the method by which all essential information could be conveyed in the most condensed possible form. It is needless to say that the Commission desires your opinion not only upon these plans, but upon any variation of them, or upon any entirely different plan which may suggest itself to you. It requests your views as to what plan it is most expedient, all things considered, for the United States to follow in the completion of the Panama Canal.

Yours, very respectfully,

T. P. Shonts, *Chairman.*

The order of the President required that there be submitted to the Board for its consideration and discussion "the various plans proposed to and by the Isthmian Canal Commission." The Commission transmitted to the Board:

1. A plan prepared by the old commission on isthmian routes, created in pursuance of the act of Congress approved March 3, 1899.

2. A plan proposed to the New Panama Canal Company November 16, 1898, by the Comité Technique assembled by that company.

3. Three projects prepared by Mr. Lindon W. Bates, of New York.

4. The more important results of recent surveys, containing the principal information available for a decision respecting a canal at tide level.

There was also submitted a paper prepared by Mr. P. Bunau-Varilla, explaining a method of construction of a lock canal to be subsequently transformed to one at sea level.

At a subsequent meeting there was received from the Commission a paper entitled "The Panama Canal: Some serious objections to the sea-level plan," prepared by Maj. Cassius E. Gillette, Corps of Engineers, U. S. Army, and another entitled "The Gatun Dam," prepared by Mr. C. D. Ward, C. E.

On the other hand, the Board received no plans originating with the Commission. Therefore, and because the requirements of the act of Congress respecting the dimensions and capacity of the canal, together with the new information collected by surveys and examinations conducted during the last two years prevented the adoption of plans of former commissions, the Board was obliged to prepare plans and estimates based on such information and on other data collected at its request, and to act as a creative body as well as a consulting board.

In order to conduct its business systematically the Board determined to hold regular stated meetings at such times as the work required, and thirty of such meetings have been held. The proceedings of these meetings were recorded and the minutes will be found as Appendix A to this report. Although these meetings were executive in character, the members of the Isthmian Canal Commission were invited to be present at any or all of them, an invitation which was frequently accepted. To facilitate the work of the Board there were appointed:

An executive committee, consisting of the Chairman, General Abbot, and Mr. Hunter.

A committee on the preparation of plans for a sea-level canal, consisting of the Chairman, Messrs. Guérard, Hunter, and Burr, to which Messrs. Parsons and Quellennec were subsequently added.

A committee on the preparation of plans for a lock canal, consisting of the Chairman, Messrs. Stearns, Tincauzer, and Ripley, to which General Abbot and Mr. Noble were subsequently added.

A committee on unit prices for purposes of estimate, consisting of Messrs. Parsons, Welcker, and Randolph.

On September 11 the President received the Board at Oyster Bay, and addressed them as follows:

What I am about to say must be considered in the light of suggestion merely, not as direction. I have named you because in my judgment you are especially fit to serve as advisers in planning the greatest engineering work the world has yet seen; and I expect you to advise me, not what you think I want to hear but what you think I ought to hear.

There are two or three considerations which I trust you will steadily keep before your minds in coming to a conclusion as to the proper type of canal. I hope that ultimately it will prove possible to build a sea-level canal. Such a canal would undoubtedly be best in the end, if feasible, and I feel that one of the chief advantages of the Panama route is that ultimately a sea-level canal will be a possibility. But while paying due heed to the ideal perfectibility of the scheme from an engineer's standpoint, remember the need of having a plan which shall provide for the immediate building of a canal on the safest terms and in the shortest possible time.

If to build a sea-level canal will but slightly increase the risk, and will take but a little longer than a multilock higher-level canal, then of course it is preferable. But if to adopt the plan of a sea-level canal means to incur great hazard and to insure indefinite delay, then it is not preferable. If the advantages and disadvantages are closely balanced, I expect you to say so. I desire also to know whether, if you recommend a high-level multilock canal, it will be possible after it is completed to turn it into or to substitute for it, in time, a sea-level canal without interrupting the traffic upon it. Two of the prime considerations to be kept steadily in mind are—

(1) The utmost practicable speed of construction;

(2) Practical certainty that the plan proposed will be feasible—that it can be carried out with the minimum risk.

The quantity of work and the amount of work should be minimized so far as is possible.

There may be good reason why the delay incident to the adoption of a plan for an ideal canal should be incurred; but if there is not, then I hope to see the canal constructed on a system which will bring to the nearest possible date in the future the time when it is practicable to take the first ship across the Isthmus; that is, which will in the shortest time possible secure a Panama waterway between the oceans of such a character as to guarantee permanent and ample communication for the greatest ships of our Navy and for the largest steamers on either the Atlantic or the Pacific. The delay in transit of the vessels owing to additional locks would be of small consequence when compared with shortening the time for the construction of the canal or diminishing the risks in the construction.

In short, I desire your best judgment on all the various questions to be considered in choosing among the various plans for a comparatively high-level multilock canal, for a lower-level canal with fewer locks, and for a sea-level canal. Finally, I urge upon you the necessity of as great expedition in coming to a decision as is compatible with thoroughness in considering the conditions.

On September 27 the Board visited the Wachusett dam and other works in Massachusetts constructed by the Metropolitan Water and Sewerage Board, and on September 28 sailed for the Isthmus, where the work already done and in progress was thoroughly inspected and the conditions affecting the type of canal and future construction examined and considered.

Messrs. P. Bunau-Varilla and Lindon W. Bates, who, through the Isthmian Canal Commission, had submitted projects for canals, appeared before the Board and further illustrated their projects by oral explanations. The explanations, subsequently revised by the authors, appear in an appropriate place in the appendix to this report. (Appendixes F and G.)

The Board invited Mr. John F. Wallace, who had acted as chief engineer to the Commission from June 9, 1904, to June 30, 1905, to appear before the Board and give it the benefit of his experience and study. This invitation was accepted by Mr. Wallace, and his communications, both written and oral, are given in full in Appendix J. These communications are of great value as embodying the results of the longest continuous study by one man since the taking over of the work by the Government, and consideration of them is therefore invited.

While on the Isthmus the Board invited Mr. John F. Stevens, the present chief engineer to the Commission, to appear before the Board and aid it with such information as he had or such

suggestions as he might care to offer. His testimony is given in full in Appendix J, wherein it is stated that since he had been connected with the work only two months, during which time his whole attention had been given to matters of organization, he had given no consideration to the cost or type of canal, and therefore had no advice to offer. Mr. Stevens gave all the information he had at hand.

There also appeared before the Board while on the Isthmus, or subsequently at Washington, Messrs. Dauchy, Maltby, and Dose, division engineers, and Mr. Bertoncini, expert draftsman in charge of the French engineering records on the Isthmus, and their remarks are attached hereto (Appendix J). Col. W. C. Gorgas, U. S. Army, chief sanitary officer, gave the members of the Board the benefit of his great experience with tropical diseases, especially those most to be feared at Panama.

After the return from the Isthmus and the receipt of the additional information asked for by the Board, the question of the type of canal to be recommended, the character and size of the channels, locks, harbors, and other works, and the cost of the same, both in time and money, were considered by the Board.

As a basis for all plans the Board resolved by eleven affirmative and two negative votes that locks should have as minimum usable dimensions a length of 1,000 feet, a width of 100 feet, and a depth of 40 feet. The two members voting in the negative were Messrs. Noble and Ripley. The Board also decided unanimously that in order to make its estimates comparable in respect to totals with the estimates of previous commissions there should be added to the estimated cost of construction an allowance of 20 per cent to cover administration, engineering, and contingencies; but exclusive of interest during construction, sanitation, expense of Zone government, and collateral costs. The Board also decided not to attempt to make any estimate of cost of the lands to be flooded by the canal or lakes in connection therewith, on account of the impossibility of procuring any reliable data upon which to base such estimates. The Board wishes to point out, however, the possibility of such cost assuming large proportions, especially if lands near the terminal cities or lands including the larger interior villages should be required.

The Committee on Sea-Level Canal submitted a project for a canal, a description of which is given in full in another part of this report, from which it will be seen that in accordance with the instructions of Congress that the canal "shall afford convenient passage for vessels of the largest tonnage and greatest draft now in use and such as may be reasonably anticipated," the committee recommend a canal whose dimensions, both as to width and depth and consequent cost, exceed similar dimensions heretofore recommended by other commissions.

The Committee on Lock Canal submitted four projects to the Board:

Project No. 1 contemplates a summit level at elevation 85 feet, to be maintained by a flight of three locks at Gatun on the Atlantic side, and with one lock at Pedro Miguel and two locks in flight at Sosa Hill adjoining La Boca pier on the Pacific side, the estimated cost of which is $141,236,000.

Project No. 2 is the same as No. 1, except that on the Pacific side there are two locks in flight at Pedro Miguel and one at Miraflores rather than at Sosa. The estimated cost of this project is $148,272,000.

Project No. 3 is based on an elevation at summit level of 60 feet, maintained on the Atlantic side by a flight of two locks at Gatun and on the Pacific side with a single lock at Pedro Miguel and another at Miraflores. For the purpose of control of the Chagres River and to furnish a water supply there is included a dam at Gamboa. The total estimated cost of this project is $171,190,000.

Project No. 4 proposes a summit level at elevation 60 feet, to be maintained by a dam with single locks at Gatun and Bohio on the Atlantic side, and with single locks at Pedro Miguel and Miraflores on the Pacific side, with a dam at Alhajuela, at a total estimated cost of $175,929,720.

All elevations are stated with reference to mean sea level.

These four estimates include 20 per cent for contingencies.

It is well to note that in each of the above projects the proposed terminus of the canal near Panama differs from the terminus proposed in the sea-level plan, and is in each case less convenient.

In the above estimates no allowance is made for the value of lands overflowed by the lakes to be formed by the proposed dams at Gatun, Bohio, La Boca, Gamboa, or Alhajuela. On the other hand the estimates do include duplicate locks at all places, whether single or in flights of two or three. In submitting these projects to the Board the committee stated that it made no recommendations, the committee having been divided in its preferences. In a separate report, given elsewhere in detail (Appendix P), the committee agree as to the impracticability of converting a lock canal to one at sea level, in the immediate future, on account of the difficulty and danger of the operation and of the excessive cost. This view was concurred in by the Board.

After considering the four types of lock plans submitted by the committee, the Board determined, by a vote of eight to five, to adopt, for comparison with a sea-level canal, a canal the summit level of which should be at elevation 60 feet, the vote in the affirmative being Messrs. Hunter, Welcker, Guérard, Tincauzer, Abbot, Burr, Parsons, and Davis, and in the negative Messrs. Ripley, Randolph, Stearns, Quellennec, and Noble. The Board decided that on the Pacific side there should be one lock at Sosa and one at Pedro Miguel; on the Atlantic side that there should be one lock at Gatun and one at Bohio, all in duplicate; and that there should be a dam for the regulation of the Chagres at Gamboa identical with that proposed for a sea-level canal. This plan is attached to and described in another portion of this report (p. 35). It is to be noted, however, that this plan, like the plans submitted by the Lock-Canal Committee, is not the most feasible which could be devised for subsequent conversion to sea level, the Board believing that such conversion would probably not be carried out. A motion to adopt such a type of lock canal by placing the locks immediately next to the continental divide, probably near Obispo on the Atlantic side and at Miraflores on the Pacific, with the canal constructed at sea level between such locks and the oceans, was defeated.

In regard to the question of time required to construct these two proposed canals, the Board resolved by a vote of seven (Messrs. Hunter, Welcker, Guérard, Tincauzer, Burr, Parsons, and Davis) to six (Messrs. Ripley, Randolph, Stearns, Quellennec, Abbot, and Noble)—

That the Board declare in its report that the time of finishing the sea-level canal depends on many contingencies that can not be definitely estimated in time; that under efficient management and not seriously affected by extraordinary and unforeseen difficulties, political obstructions, or bad sanitation it may be regarded as feasible to complete the work in about twelve or thirteen years; that adverse conditions may lengthen that period, while favorable circumstances and continuous first-class direction may make it possible to shorten that period by one or two years.

It was unanimously resolved in language similar to the resolution in connection with the sea-level canal that the canal with locks on the plan prepared by the Board may be constructed in the period of ten to eleven years.

The Board having adopted a type of sea-level canal and a type of canal with locks as seemed most suitable under all conditions involved, and having decided that it was not expedient to adopt any of the plans which had been submitted or proposed to the Board, the following resolution was moved and adopted by a vote of eight to five, those voting in the affirmative being Messrs. Davis, Parsons, Burr, Hunter, Guérard, Quellennec, Tincauzer, and Welcker, and those in the negative being Messrs. Abbot, Noble, Stearns, Randolph, and Ripley:

Whereas in the judgment of this Board, a sea-level canal is feasible, following a line with dimensions and such arrangements that the transit between the two oceans shall be secured in a permanent manner for all time under the best conditions for navigation and safety, for vessels of the largest tonnage and greatest draft now in use, or such as may be reasonably anticipated: Therefore

Resolved, That the Board adopt and recommend to the President of the United States the plan of a sea-level canal with a depth of 40 feet, a width in rock of 200 feet, a minimum bottom width in earth of 150 feet, with a double tidal lock at Ancon whose usable dimensions shall be 1,000 feet in length and 100 feet in width, and with a dam at Gamboa for the control of the Chagres River.

The remarks by members explaining their votes on this resolution are given in the minutes of proceedings. (See Appendix A, twenty-fifth meeting.)

In accordance with the sense of this decision, the Board submits herewith a general plan for a sea-level canal and recommends the same for adoption.

PHYSICAL CHARACTERISTICS OF THE PANAMA ROUTE.

The combination of a very narrow isthmus with low summit is found at Panama. The route practicable for a canal there is not half as long as the Suez Canal. The portion of this route that is higher than the highest cutting at Suez is about seven miles in extent.

The drainage of the Isthmus throughout about three-fourths of its width is effected through the Chagres River and its tributaries to the Caribbean, and of the remaining one-fourth through the Rio Grande to the Pacific. The proposed Pacific terminus is about 20 miles farther east than the Caribbean terminus, for at the Panama Isthmus the trend of the two coasts, there approximately parallel, is about east and west.

The drainage to the Pacific is now effected through the Rio Grande, a small stream discharging into Panama Bay to the west of Sosa Hill and about two miles west of the city of Panama.

The tidal oscillation in Limon Bay, the initial point of the canal route, is about two feet, while at Panama it is about 20 feet. The harbors are not naturally good, but they have been made to suffice for the limited traffic seeking this route.

The geologic features of the Isthmus are very well described by two eminent French scientists, a translation of whose report on this subject, together with the deductions from the existing facts as affecting proposed engineering operations, and especially the stability of the banks of the channel and slopes, are very lucidly set forth in a paper which will be found in Appendix B, while climatic conditions are treated in the section of this report which is devoted to this important subject.

As before stated, the drainage toward the Atlantic is naturally effected through the Chagres, the canal line by all plans being located in the immediate valley of that stream for about 21 miles. One of its tributaries, the Obispo, drains the extension of the canal line for about five miles toward the Culebra summit. The Chagres is a torrential stream, and drains a basin of an estimated total area of about 1,200 square miles, about half of which is above the point where the proposed canal line leaves the river. Its sources are in the San Blas Mountains to the northeast. The course of the Chagres is, in a general way, parallel to the Caribbean coast as far as the mouth of the Obispo, where it turns to the northward and follows a somewhat tortuous but on the whole fairly direct course to the Atlantic rim of its upper basin at Bohio, about 13 miles below the mouth of the Obispo. At Gatun, about 10 miles below Bohio, following the general course of the valley, the direct distance to the Atlantic at the head of Limon Bay is only three miles, but the river deviates to the westward, and after a further course of about seven miles, passing to the west of Limon Bay, discharges into the sea at the old village of Chagres, about five miles west of Point Toro.

Above Bohio the Chagres Valley is undulating or hilly, the declivities becoming steeper toward the sources of the river, where the country is mountainous. At Alhajuela, about eight miles in a direct line above the mouth of the Obispo, the low-water surface of the river is about 95 feet above sea level, and at the mouth of the Obispo 45 feet; but at Bohio, 13 miles farther down, it is practically at sea level. From Bohio to the sea the surface of the ground for considerable areas in the vicinity of the river is but little above sea level. In this low region the Chagres receives several tributaries, of which the Gatun from the eastward and the Trinidad from the westward are of considerable size.

There are several notable topographic features of the Chagres Valley which have a very important bearing upon the canal problem. In the upper courses of the stream and its tributaries the bottom in the waterway is the original rock formation, and the channel is strewn with bowlders, pebbles, and sand which have been loosened by erosion. Borings have been made in this valley at several points from Alhajuela to Gatun, with a view of determining the character of the earth and depth to rock. It is found that at Alhajuela there is a depth of about 29 feet of gravel overlying the rock in midstream. The rock outcroppings in the bluff appears to be of a firm and homogeneous structure, of volcanic origin. At this point the hills on either side contract the valley in a marked degree. At Gamboa, which is just above the junction of the Obispo, the

gravel covering of the rock bed is about 50 feet in depth. At San Pablo the bed of gravel, sand, etc., is about 90 feet in thickness; at Buena Vista it is over 139 feet below sea level to rock, and a little farther downstream, 142 feet; at Bohio the rock is 168 feet below tide level, and the drills penetrated wood at various depths to 150 feet. At Gatun, the depth to what in this report is sometimes classed as rock—an indurated sandy clay—is 258 feet in the deepest place, and at another, on the same section, the depth of the sand, clay, gravel, etc., is about 240 feet. Here also buried wood was brought up by the drills.

It seems, therefore, to be certain that what may be called the geological valley of the Chagres—that is to say, the rock bottom of that stream—is represented by a deep groove or channel, now entirely or partly filled by the products of erosion and drift. If there has been a regional subsidence of the Isthmus, which the geologists suggest as possible, it may be that the ancient Chagres discharged into the sea through an ancient valley, which, with the land adjacent thereto, was some 300 feet higher in relation to the ocean than the present valley. The rock penetrated at Bohio and above, also that showing in the river banks and outcropping in neighboring hillsides, is all volcanic and much denser than the so-called rock at Gatun.

The Obispo flows over a rocky bed in a part of its lower course and at one point there is a natural cascade of a few meters over a rock shelf. The general surface on the upper course of the Obispo is more nearly level, with hills rising in its drainage basin and on its margins to the height of from 100 to 1,000 feet above the general surface. The general aspect of the central isthmus is one of great irregularity—the hills are numerous and have very steep slopes, while the valleys are narrow. Culebra is one of these hills, its summit being some 700 feet above the sea. The geologists suggest that the drainage area of the upper Obispo was once a lake of considerable size, for within this area are found a few sedimentary rocks containing fossils, also calcareous and carboniferous deposits, but the greater part of the material is of volcanic origin, the central masses of the hills containing hard volcanic rock and dikes of basalt.

Between, above, and below these hard-rock masses are softer rock and dark, indurated clay, while the upper covering of the superficies is composed of the same volcanic material, but much changed by exposure to the weather, and where cut through, as it is by the canal excavation all the way for seven miles through the dividing ridge, the covering is seen as a red clay, occasionally containing bowlders, having a varying thickness to 30 feet and at one place to more than 40 feet, but generally its thickness is but 10 to 20 feet. It is in this top layer of reddish clay that all the larger slides have taken place.

Toward the Pacific the slope is, for half the distance to the bay, much more rapid than in the Chagres Valley, but the physical characteristics are similar. The Rio Grande Valley, through nearly half its length, is a tidal estuary filled and emptied twice daily by the tides. The same or a similar rock to that showing in the upper Chagres Valley is the prevailing rock in the Rio Grande region, with but a few feet of earth covering. At Pedro Miguel and Miraflores the rock is near the surface. Near Panama are two isolated hills of considerable height showing volcanic rock outcrops of a very much denser character than any other on the Isthmus.

The facts being as stated, it follows that the streams draining the isthmian region have a much more permanent regimen in their upper courses than nearer the sea. The rock near the surface a few miles from the oceans is conveniently situated for foundations for locks, dams, etc., and is sufficiently dense to make good concrete material, while sand suitable for use in masonry structures is found in great abundance on the beaches of Panama Bay, and probably that found in some of the gravel beds in the Charges will also be suitable for the same purposes.

The hill and mountain slopes are covered with a tropical jungle, but there is no good timber for construction purposes found on the Isthmus near the railway.

CLIMATE.

The climate of any locality is determined by certain influences, the principal of which are latitude, altitude, proximity of oceans, high mountain ranges, humidity, and rainfall.

A detailed description of the climate of the American Isthmus is quite unnecessary, for it is well known, but its adaptability as a residence for human beings employed in manual labor or

in a supervisory capacity is not generally very well understood. The state of the atmosphere respecting heat and moisture and meteorological conditions generally has a very important influence upon the health and contentment of the inhabitants.

That this question of climate has a very important bearing on the canal problem is acknowledged by all who have carried on engineering works in tropical countries and by those who are familiar with the history of such operations.

Temperatures at the Isthmus as low as 72° or as high as 98° are unusual. It is correct to say that the average daily range of the thermometer is from 75° to 84°. The highest recorded temperature in the Chagres Valley is 97° and the lowest 64°. The number of days in the year when the heat at night is less than 75° and greater by day than 84° are very few. In other words, the daily range in temperature is only about 10°, with little variation between summer and winter, wet and dry seasons. But the atmosphere is generally quite damp, ranging in relative humidity from 80 per cent in the dry season to 87 per cent in the rainy season. With a temperature of approximately 80° and a relatively high humidity the air is damp and muggy, and therefore exhausting and oppressive to the white race unaccustomed to tropical conditions. These conditions are common to many tropical regions near the sea level.

The rainfall on the Isthmus is greater than in some parts of the tropics and much less than in others, the annual precipitation varying from about 140 inches at Colon and the lower Chagres Valley to 95 inches in the interior and to about 70 inches on the Pacific side. But the precipitation is very unequally distributed throughout the year. During the four dry months—January, February, March, and April—and the eight wet months the average monthly rainfall and the average yearly total are as follows:

	Atlantic side and Chagres Valley.	Interior.	Panama, Naos, and La Boca.
	Inches.	*Inches.*	*Inches.*
Dry season	3.7	1.56	1.74
Rainy season	15.3	11.08	7.89
Total for year	137.2	94.87	64.70

These data are the result of observations covering a period of 33 years at Colon, 21 years at Gamboa, and from 3 to 10 years at the points on Panama Bay. The heaviest rainfall in any one month was 20.9 inches at Colon.

The number of days given in each year from 1889 to 1904 during which there was some fall of rain was, at Colon, 196; Bohio, 246; Alhajuela, 198; Gamboa, 190; La Boca, 141; but on many of these days the fall at all points was very slight.

It is well known that high winds having the character of hurricanes are very rare at the Panama Isthmus. Northers occur at rare intervals in the Caribbean. One or two of considerable violence have at times been felt in a year at Colon. Sometimes a whole year passes without a wind of greater velocity than a strong breeze; on the other hand, northers have occurred in which the wind velocity has reached 50 miles an hour, but there have been no accurate measurements made of these storms. These blows are never felt in the interior or on the Pacific side.

The observed monthly mean velocity of the wind at Colon from October, 1898, to May, 1899, varied from five to eight miles per hour, the maximum monthly mean observed being eight and one-half miles, while the strongest observed on any day in eight months was 24 miles. There is generally a pleasant breeze every day from a northerly quarter, and this applies throughout the Isthmus. At Panama there is no record of a severe storm of any kind, and the winds are generally from the north and offshore.

A member of the Board, who since 1898 has resided nearly six years in the tropics, one year of which was spent at Panama, stated that he had observed no marked difference between the climate of Panama and that of other tropical countries.

SANITATION AND HYGIENE.

The Isthmus of Panama was not well known to the inhabitants of the United States until it became a favorite route of travel for the California immigration after the discovery of gold in the Sacramento Valley in 1848. Since then this route has been much used, not only by Americans but by Europeans and the inhabitants of the west coast of Central and South America.

After the gold discovery lines of steamers and sailing vessels on both oceans conveyed travelers to and from the Isthmus, the transit at first being effected by canoes on the Chagres River in connection with riding and pack animals between that stream and Panama Bay. The transfer from the Caribbean to the Pacific occupied from five to ten days, and very often much exposure and suffering resulted. In the light of present knowledge respecting the cause of yellow and malarial fevers it is not surprising that sickness and mortality were experienced among those who traversed the Isthmus in those early days. What has been called Chagres fever is now recognized as a malignant type of intermittent fever, otherwise known as malaria, which, as well as yellow fever, is believed by sanitarians to be communicated to man only by certain species of mosquitoes.

What the extent of the mortality among those early travelers was we do not know, but judging from what history records respecting the frightful losses among the French and English troops serving in the West Indies during the eighteenth and first half of the nineteenth centuries, particularly in Santo Domingo, Cuba, Nicaragua, and the Lesser Antilles, we can very well believe that the suffering on the Isthmus in the early days was very great, for the emigrants hurrying to California were but ill provided against hardships, were ignorant of the conditions, and were not controlled or governed by any constituted authority.

The construction of the Panama Railroad was undertaken in 1850, but the promoters of that enterprise understood local health conditions no better than did those who had preceded them. Workmen from the United States who were entirely unacclimatized were employed in large numbers and many succumbed to the local fevers, others to exposure and diseases due to intemperance and disorderly living. The road was open throughout its 45 miles in 1855, and thereafter the California immigration was spared the difficult canoe navigation of the Chagres and the land journey between Cruces and Panama.

It has been often stated that the mortality among the railroad workmen reached an aggregate which equaled in numbers the cross-ties used in the railway roadbed—that is to say, 150,000—but the chief engineer of that road, the late Col. George M. Totten, stated repeatedly that the total number of persons employed in building the road never exceeded 7,000 at any one time, and that the number of laborers and workmen who died in the whole five years did not exceed 1,200 in all.

To what extent yellow fever figured in those statistics is not known, but as this disease was then prevalent throughout the American tropics and warmer temperate latitudes there is little doubt that it was one of the principal causes of sickness. There is no doubt whatever that malarial fevers of all types—intermittent, malignant, and pernicious—were prevalent.

From 1855, the date of opening the all-rail route across the Isthmus, to 1881, when work was begun on the Panama Canal, the transit was used for transferring travelers, freight, mails, etc., between the Atlantic and Pacific oceans, and nearly all the superior employees of the corporation were Americans, but the annals of the Isthmus give us very little information respecting health conditions. We know that during this quarter of a century some hundreds of thousands of travelers used the transit, and many hundreds of citizens of the United States were employed by the company in operating its road. Some of these men remained on the Isthmus ten or twenty or more years and enjoyed good health. At the time the United States took over the Panama Canal there was a very considerable number of Americans employed on that road, who continued strong and vigorous when they observed ordinary sanitary rules. Of course they were well sheltered, their food was adequate and suitable, and medical attention and hospital treatment, with medicines, were available.

Work on the canal was begun in 1881. In 1882 the force employed was 1,910, and in 1884 the average number for the year was 17,615, although the maximum was 19,243, in October. The aggregate of the numbers of those reported yearly as employed in the whole period is 86,812, or an average of 10,881 per year. By computation it is found that the total number treated for sickness during the eight years was 52,814. It is also found by reference to Tables 1 and 2, recently compiled (see Appendix O), that the number of deaths of employees in the same period was 5,627, showing a rate of mortality among the sick of 10.62 per cent, and among the employed of 6.48 per cent. These important data, together with the recently compiled statistics for the city of Panama never yet published, are a very valuable contribution to our knowledge of the health conditions as they formerly existed on the Isthmus, not only during the activity of the old company but also for the years which have since elapsed, for the system of recording vital statistics instituted in 1881 has been continued to date.

The methods adopted by the health authorities on the Isthmus twenty years ago for combating tropical diseases which caused great sickness and mortality were such as were deemed most effective by the sanitarians of the period. The French company erected fine hospitals of large capacity, with up-to-date equipment, and their physicians and nursing force were competent and efficient, but modern methods for preventing sickness were then unknown. The old company, a private corporation, had no power to compel observance of health ordinances by the resident population, or by their own employees. The local authorities and permanent residents of the Isthmus were immune to yellow fever, and the people and municipal authorities were indifferent. Yellow fever was believed to be due to a poison, ever present, to which a certain proportion of newcomers, especially Europeans, was expected to succumb, as they had always done. It was believed that the disease was contagious and that the malady was transmitted by personal contact with the sick or their excreta, and the preventive measures employed to protect the new arrivals consisted of attempts at isolation of the sick, as is now done with those afflicted with smallpox.

Malaria was believed to be caused by a miasma exhaled from the soil or by decaying vegetation, and it was accepted that newly upturned soil caused the disease to spread. As the name implies, the disease was believed to be due to bad air. But discoveries of the very greatest importance to the human race have put an end to these misconceptions, and malaria and yellow fever are no longer a mystery to science. The mosquito theory of the transmission of these two diseases is now generally accepted as the solution of the mystery by all the leading sanitarians and physicians.

The knowledge of the discoveries of Reed, Lavaran, and Ross has been given world-wide publicity, and gradually has been accepted and acted upon in many parts of the world.

The yellow-fever record on the Isthmus since the United States took over the canal works is as follows: In May, 1904, there was 1 case; in June, 1; in July, 2; August, none; September, 1; October, 1; November, 3; December, 6; January, 1905, 18; February, 14; March, 11; April, 9; May, 33; June, 62; July, 42; August, 27; September, 7; October, 3; November, 5, one of which was from a point 30 miles distant, making a total in the nineteen months of 246 cases. Of these, 84 terminated fatally, or about 34 per cent.

Commenting upon these figures, Col. W. C. Gorgas, U. S. Army, the chief sanitary officer of the canal works at Panama, remarks in his October report as follows:

> I consider this (the October record) as indicating the near approach of the disappearance of the disease. * * *
>
> Panama has often in its past history been free from yellow fever, but the only disappearance was when there were no nonimmunes to contract it. At all times in its past history when there were nonimmunes here they had yellow fever as long as the nonimmunes remained. We had during October all the natural conditions favorable to this disease, a larger number of nonimmunes probably than had ever before been present on the Isthmus—in the neighborhood of 5,000—with a wet and hot month.
>
> Apparently, from the records, the season in Panama does not have much influence upon yellow fever. The weather in January is as favorable to the breeding of the Stegomyia as July, and the past records seem to show that if we have nonimmunes in Panama in December we will have as much fever as we would in July. It has altogether in the past depended upon the supply of nonimmune human beings. The only yellow-fever period when there was anything near to approximating as many nonimmunes on the Isthmus as we have at present was at the time during

the French régime when they had their maximum force. This occurred in October, 1884, when they had 19,243 men on their rolls, of whom 2,706 were nonimmunes. Among these they had 21 deaths from yellow fever in that month and approximately 84 cases. During October of this year our force has also reached its maximum, about 22,000,[a] of which number about 4,000 are nonimmunes. Among these 4,000 employees we had not a single death from yellow fever and only a single case. Of the three cases occurring on the Isthmus, two were people not employees of the Commission.

Here we are comparing two periods in which there was a large number of nonimmunes present—the same season of the year and the same climatic conditions generally—the only difference being that in the year 1905 modern tropical sanitary methods were enforced all over the Isthmus by some 2,200 men. * * * Twenty years ago these methods were unknown, malaria and yellow fever were a mystery to science, and our predecessors were unable to do anything for their control.

The results obtained, I maintain, are solely and entirely due to the sanitary measures put in force. And be it remembered at the same time that we have at present with us fully one-third more people subject to yellow fever (nonimmunes) than the French had in October, 1884.

You can pick out in the history of Panama Octobers when there were no deaths from yellow fever, such as October, 1901, or October, 1895, or October, 1896; but during these Octobers there was nobody in Panama who could have yellow fever. Take any other October when there was present any considerable number of nonimmunes and they always had yellow fever to a considerable extent. In this October when we have more people liable to the disease than ever before we had only three cases.

* * * * * * *

The showing with respect to the sick rate of employees generally is very good. Among 22,000 men we have a daily average of about 450 in hospital. This gives us a constant sick rate of 21 per thousand. We could not hope to show a lower rate than this if our canal were being dug between Washington and Baltimore. The French in October, 1884, with their 19,243 employees, had 161 deaths, making a rate for that year of 100 per thousand. We, with a force of about 22,000, have had 61 deaths, which would give us for the year a death rate of 32 per thousand. I have no doubt that when the sanitary improvements at present going on, such as street paving in Panama and Colon, waterworks in these cities and along the line, and comfortable screened buildings for employees at all points, shall have been completed the health conditions will be still further improved; but I am inclined to think that the sanitary question of Panama has been settled, as we have shown that a force of laborers as large as we are likely to have and as unfavorably situated as they ever will be can work on the Isthmus without suffering from yellow fever, and that the general health of this same force can be kept as good as if they were digging a canal in a healthy part of Maryland.

In the city of Panama it is a requirement of law that all burials shall take place in the city cemetery, and that the records of burials shall show the name, age, sex, nativity, cause of death, and the name of the physician certifying to cause in every case. These records have been carefully kept since 1882, and the chief sanitary officer of the Canal Zone has recently had every individual record of burial for the city of Panama examined, tabulating the result so far as it relates to those who succumbed to yellow and malarial fevers. The result of this inspection appears in Table 3, Appendix O, wherein is set forth the mortality for those twenty-two years caused by the two fevers, the figures being given for each month of the whole elapsed period.

The stated population of the city is the closest approximation which can be obtained from the public officers of the Republic of Panama, for since 1871 there has been but one census, that of 1904 made by the sanitary staff of the Canal Zone.

During this period of twenty-two years there were three or four occasions when there was an influx to the Isthmus of a large nonimmune population. The first was in 1881–82 and continued to 1889. The next was in 1895 when a regiment of troops from the interior highlands of Colombia arrived for service on the Isthmus. The next year there was another increase of military force from the same locality, those men also nonimmunes. The last was in 1901 when there was a further large increase consisting of a body of Colombian troops sent to Panama to operate against insurgents. On each of these occasions there was a large increase in the mortality from yellow and malarial fevers, as may be seen by the table. During the intervening months or years there were very few cases. The rule held true continuously until full effect was had from the sanitary measures taken by the United States health authorities in the Canal Zone, but it required a year and a half to secure full beneficial effect of the preventive means adopted. The records of the Panama cemetery are cited by the United States health authorities as furnishing evidence

[a] Including those employed on the Panama Railroad.

of the accuracy of their declaration that it is not only possible but feasible to banish yellow fever from the Isthmus and to maintain the whole force of employees in a good state of health.

A few years ago the abandonment, as a canal headquarters, of the city of Ismaïlia, situated on the line of the Suez Canal, was seriously considered because of the general sickness of the European inhabitants and the canal officials. The population was 9,000, of which the European inhabitants were 2,000. Among these there were 1,400 cases of malarial fever annually, of which many resulted in death. The mosquitoes (anopheles) were killed and their breeding places destroyed in 1902. The number of cases of malaria since has been, yearly, 214, 90, and in ten months of 1905, 46, with no deaths. Those who have had malaria subsequent to the sanitating of the place are those who had been chronic sufferers from the disease previously.

Recent reports received by the Commission contain interesting data concerning general health conditions, from which much knowledge is gained respecting health and disease, and indicate that the maladies prevailing on the Isthmus are generally the same as are common in the temperate climates.

In the largest hospital in the Zone, that at Ancon, there were treated in October 1,118 persons. Included in this number there were eight cases of typhoid fever, a very small number considering the population of the Zone—a total of 63,084—and the squalor, indigence, and indifference to sanitary rules of a large part of the inhabitants. In this hospital there were 19 cases of dysentery, 30 of beriberi, 17 of pneumonia, 6 of bronchitis, 4 of consumption, 15 of venereal diseases, 6 of measles, 19 of piles and hernias, 33 abscesses, 24 wounds, and 13 of general debility. There was no case of either smallpox or plague.

In the whole Zone, including the cities of Panama and Colon, there were deaths as follows: Ninety were from fevers of all kinds; beriberi claimed 26; dysentery, 9; cerebral hemorrhage, 6; convulsions (children), 6; tetanus, 4; consumption, pneumonia, and bronchitis, 92; gastric disorders, 33; liver diseases, 5; genito-urinary diseases, 13; childbirth, 6; accidents, 9; dropsy, 7; heart diseases, 5.

To the ordinary observer the appearance of the city of Colon is much worse than that of Panama, yet its record for disease is better. Yellow fever has been comparatively rare there. Its better record may be due to its situation on an island, the surface of which is awash with sea water throughout a considerable part of its superfices. We are told by the sanitary officers that the mosquitoes which cause yellow fever and malaria do not breed in salt water. This has significance and weight in determining the general drainage system for the canal works.

The inability of the French companies' officers to enforce sanitary rules has been referred to, but this inability was not an important matter, for the then best-known health measures, no matter how thoroughly enforced, would have accomplished little of real benefit in reducing the sick list, for no one in France or elsewhere then had any conception of the present theory respecting the cause of these two maladies which decimated the newcomers at Panama. But for the United States the situation is different. The discovery of the probable cause of yellow fever, and the knowledge of the measures adopted by sanitarians to control and prevent its ravages, have simplified the task of those who are to make the canal.

The United States not only has the right granted by treaty to enforce all necessary rules of sanitation and for the preservation of order, but the authorities of the Republic of Panama have shown the most ready willingness to cooperate and assist in the efforts taken to rid the Isthmus of disease and prevent its importation.

Notwithstanding the fact that near-by Pacific ports have for several years been infected with bubonic plague, the health officers of the Canal Zone have, by means of a rigid quarantine, so far prevented this pest from obtaining a foothold on the Isthmus, and there seems to be good reason for the confidence of these officers in their ability to exclude that disease permanently. We now know that men from temperate climates living in the tropics, including Panama, can and do escape the great danger which twenty-five years ago could not be evaded, and that the danger does not appear to be greater than exists in many parts of the United States.

WORK DONE AND PRESENT CONDITIONS.

The present state of the canal work is but little different from that in which the old Panama Canal Company left it in 1889. The liquidator, who had control of the assets of the company under the decree of the French court from 1889 to 1894, did no work on the Isthmus other than that of preserving the property under his care. When the New Panama Canal Company was incorporated in 1894 it recommenced the work of excavation at the divide on a small scale and maintained those operations, with a force varying from a maximum of 3,800 men to a minimum of a few hundred, until the property was taken over by the United States Government in May, 1904. That company performed no other work in furtherance of the actual construction of the canal than the continuation of excavation at the summit divide and the dredging of about 3,000,000 cubic yards at the La Boca pier and approach thereto, although it maintained a sufficient force to care for the mass of materials and plant stored along the line of the canal.

The total work actually performed upon the canal can best be appreciated by keeping in view the plans contemplated by the French companies. In accordance with the decision of the International Scientific Congress held at Paris in May, 1879, the old Panama Canal Company adopted a sea-level plan for the canal. When, however, it became apparent that it would be financially impossible to carry out the work on that plan, a number of projects with locks and with various summit elevations were carefully considered. It was the purpose at that time to devise a project which would permit lock-canal navigation to be opened at the earliest possible date, and by the subsequent removal of the locks to ultimately realize the original conception of a canal at sea level. While these modified projects were under consideration the collapse of the old company occurred and all work ceased.

All subsequent studies conducted both by the liquidator and the New Panama Canal Company were also directed to the determination of lock plans. Both the Commission d'Études, created by the liquidator, and the Comité Technique, appointed by the New Panama Canal Company, rejected the sea-level plan and devoted their efforts to the development of a lock plan best adapted to the limiting financial conditions under which the new company would have to complete the work. The Comité Technique finally recommended a plan for a canal with a maximum summit elevation at nearly 101 feet above the sea, the bottom width of the canal being 98.4 feet in earth and 111.5 feet in rock, and with a minimum depth of water of 29.5 feet. This plan required a double flight of two locks at Bohio and another similar arrangement of locks at Obispo on the Caribbean side of the continental divide. On the Pacific slope there were contemplated duplicate single locks at Paraiso southerly of and close to the great Culebra cut, a double flight of two locks at Pedro Miguel, and duplicate single locks at Miraflores, the latter being partially tidal locks, in order to control in the canal the varying heights of the tide in the bay of Panama. In connection with these locks the plan included a Caribbean sea-level section 14.84 miles long; an intermediate level between Bohio and Obispo 13.37 miles long, in which the water surface would vary in elevation from 52.49 feet to 65.62 feet above the sea; a summit level 6.22 miles in length from Obispo to Paraiso with a maximum elevation of 100.89 feet; an intermediate level 1.32 miles long from Paraiso to Pedro Miguel with a water surface at a maximum elevation of 76.28 feet; another intermediate level 1.32 miles long from Pedro Miguel to Miraflores with a maximum elevation 20.51 feet above mean tide, and a Pacific sea-level section 7.38 miles in length, the lengths of the various levels being given exclusive of the lengths of locks. The excavation made by the New Panama Canal Company at the summit was continued, to serve the execution of this plan, although it was thought possible that a lower summit level at 65.5 feet above the sea might ultimately be adopted, so as to eliminate the locks at Obispo and Paraiso.

There was also contemplated by the New Panama Canal Company the creation of a large reservoir for feeding the summit level of its adopted plan by constructing a masonry dam across the Chagres River at Alhajuela, about 11 miles by the feeder line from Obispo. A feeding canal, or aqueduct, with suitable appurtenances, was to be formed on this line in order to connect this reservoir with the summit level above Obispo. No work, however, was ever performed either

in the construction of the dam or on the line of the feeder, but surveys and investigations were made and the necessary works were all completely planned.

The old Panama Canal Company made extensive surveys and soundings, and erected many buildings, shops, hospitals, etc., but confined its operations along the canal line wholly to the work of excavation, except for the construction of a small dry dock near the Colon terminus, and some docks or piers in the same vicinity required for the discharge of materials and machinery shipped to the Isthmus for the purposes of the work.

The country along the canal line from Colon to Obispo is nearly all low, in places marshy, and the material can generally be removed by dredging. The old company availed itself of this physical condition and, with the exception of Culebra, the greatest volume excavated in a limited distance was confined to this portion of the line. Between Cristobal Point (behind which the old company planned its canal entrance) and the mouth of the Mindi, a distance of about three miles, there is a small quantity of coral rock and a much larger quantity of hard sandy clay, which may be classed as soft rock, still remaining in place.

The depth of the excavation near Mindi and at one or two other points was about 29 feet below sea level; but the average depth for about one-half the distance from Colon to Bohio was not more than two-thirds of that amount below mean tide, while the depth of excavation for the remainder of the distance under consideration did not vary much from 25 to 27 feet. On account of the rising surface of the ground the depth below sea level was but a few feet at a distance of two miles from Bohio and decreased to nothing at that point. This stretch of canal, about 11 miles long, with an original bottom width of about 72 feet, is still open, although some sediment has been deposited, and can be navigated throughout its entire length, save at one point, by vessels drawing from eight to ten feet, and much more in that portion of it between Mindi and Gatun.

In consequence of the fact that this portion of the canal line intersects the Chagres River at a number of points, thus forming a direct course, and for the further reason that diversion channels and small dams have been constructed, the water of the Chagres River flows through this excavated channel from a point about two miles below Bohio to Gatun, a distance of about seven miles. From Gatun its flow divides, a part of it, estimated as one-third at ordinary stages of the river, passing to the sea in the old channel and the remainder flowing into Limon Bay through the canal channel and the mouth of the Mindi. The portion of the old company's canal work between Colon and Bohio and the work of excavation in the Culebra cut are the two largest and most impressive features of the accomplished work in its present condition.

At Bohio an extensive mass of volcanic rock outcrops. This rock has been used for structural purposes at Colon and along the railroad line, and in a portion of this outcrop the old canal company made an excavation of considerable magnitude for the locks which it proposed to locate there after it was compelled to abandon the sea-level plan. This excavation, like many other portions of the company's work, may be utilized in subsequent construction.

Between Bohio, 15 miles from the Colon terminus of the canal, and Miraflores, about 41 miles from the same point, the ground is relatively high, rising gradually on the Caribbean side to the continental divide at Culebra, then falling rapidly to 15 or 20 feet above sea level at the Rio Grande between Pedro Miguel and Miraflores. Throughout this distance, with the exception of that portion between Obispo and Culebra, a distance of about seven miles, the excavation made by the old company consists of a shallow but nearly continuous cutting. At several relatively high points the cuttings are deeper, but the amount in the aggregate is relatively small. From Bohio nearly to Obispo the canal line frequently intersects the course of the Chagres; but at a point a little less than a mile from Obispo the Chagres Valley trends abruptly to the northeast, almost at right angles to the line of the canal, which here follows approximately up the course of the Obispo in a southeasterly direction toward Panama. At Gamboa, less than a mile from Obispo, a short distance upstream from the point where the canal line leaves the river, both the old and the new companies at different times projected the construction of a dam for the purpose of controlling the Chagres floods and feeding the summit-level locks, but finally abandoned the idea of a dam at that site.

The present condition of the seven-mile cut through the continental divide shows that a large amount of material has been excavated in that locality, principally by the old company, but to the extent of about 7,000,000 cubic yards by the new company and nearly 1,000,000 cubic yards by the Isthmian Canal Commission during 1904–5. The maximum depth of this cutting below the original surface—333 feet above sea level—is about 165 feet. The excavated material has been deposited mainly in the Lirio marsh, about a mile northeast from the deepest part of the cut, and to a less extent in the Rio Grande Valley near Cucaracha, immediately south of the southerly end of the cutting.

The alignment adopted by the old and the new companies for the Pacific sea-level section of the canal followed approximately the course of the Rio Grande from Miraflores to La Boca. It intersected the course of the river a number of times and required small diversion channels at either side, but the Pacific terminus of the canal was practically identical with the mouth of the river. The valley of the lower Rio Grande is a salt marsh or swamp, although if the canal should be excavated to a depth of 40 feet below the sea level some rock will be encountered in the channel. The old company excavated the canal for a distance of about two miles from La Boca to an average depth of about 20 feet from the original surface, which is at nearly extreme high water. As the extreme range of tide at the Pacific terminus of the canal is from about 10 feet above mean sea level to 10 feet below, the old company planned to make the Pacific sea-level section of the canal from Miraflores to deep water 39.4 feet deep below mean tide. Less than one-third of the total requisite excavation was made between La Boca and Miraflores, nor was a channel to full depth completed by that company from La Boca to the deep water of Panama Bay. This latter work would have required the excavation of a considerable quantity of hard rock.

The old company not only excavated for the channel of the canal proper, but it also excavated diversion channels parallel with the axis of the canal on both sides of it and distributed throughout nearly its entire course, to the aggregate length of 20.2 miles on the easterly side of the canal and 13.16 miles on the westerly side. These diversion channels were constructed for the purpose generally of intercepting the flow of the streams which would otherwise discharge into the canal, and they were to be permanent features of the work. A few short lengths were designed to serve a similar purpose only during construction. The largest of these diversion channels are mostly found between Obispo and Colon, as it was necessary under the French plans to divert the entire flow of the Chagres throughout some portions of that distance. Among these is the Gatun diversion. The excavation already done in it amounts to nearly 2,700,000 cubic yards. Its length is 6.13 miles. It was designed to discharge 17,600 cubic feet per second.

The diversion channels on the easterly side of the canal line were designed with bottom widths varying from about 52.5 to 131 feet, with side slopes having in general an inclination of about 45°. The maximum depth of water contemplated in these channels was nearly 15 feet. On the westerly side of the canal line some of the diversion channels are of smaller section, varying in bottom width from about 20 feet to the same maximum of 131 feet as on the easterly side. At one point, near Obispo, a tunnel 1,203 feet in length and about 16½ feet wide and of equal height was nearly finished for diversion of the Obispo, which in flood now flows through it. A few of these diversion channels were finished, but the greater number were only partially completed. Some of them have received the waters for which they were intended and have been scoured to an increased depth, while others have been partly filled with sand or silt moved by freshets.

A total amount of about 80,000,000 cubic yards of all classes of materials has been excavated throughout the entire line of the canal, making almost continuous work from one end to the other. By far the greater portion of this excavation was soft material or earth largely removed by dredges, but a comparatively small portion of it may be classed as rock. This means that the principal portion of the remaining material to be taken out must be considered rock, and much of it as hard rock. A substantial portion of this 80,000,000 cubic yards of excavation has been so deposited along the proposed line of canal that it will have to be again moved in the work of construction, because of the greatly increased cross section of prism now required.

It is difficult if not impossible to state what portion of this excavation will be available in future construction. The entire excavation made at the divide is of this useful character, but it is probable that the aggregate of all the useful portions of the work done will not exceed 40,000,000 cubic yards.

The aggregate volume of excavation in the diversion channels will probably not exceed 5,000,000 cubic yards, but it is practically all available for the construction of a sea-level canal. The portion of the same aggregate which would be useful in the construction of a lock canal would depend upon the plan adopted.

The general location and alignment of the canal is, on the whole, satisfactory. There are places, like that in the summit cut extending from Emperador to a point near Cucaracha, where the alignment may be improved without much change of location, but necessitating increased cutting both in the hill at Emperador and that at Culebra, and an equal saving in other places. The curvature generally is sufficiently easy, the minimum radius being 8,202 feet. There is some objectionable curvature at the termini, especially near Colon, which the plan proposed by the Board will remove.

In addition to this work of excavation there were immense quantities of material, machinery, and appliances required for the prosecution of the work of construction received and distributed along the entire line. The book value of this great quantity of construction material, nearly all of which still remains upon the Isthmus in various degrees of repair, is about $29,000,000. Much of it is housed and in good order, although now nearly useless in consequence of its obsolete character, while other and larger portions of it are found exposed along nearly the entire canal in all conditions of disuse and decay.

Over 2,000 buildings—mostly houses for the employees of the old company, excellent hospitals, and some storehouses or shops—still remain, some in good condition and others in need of much repair. These buildings are generally capable of being put into service.

There are also six machine shops, some of considerable capacity, the principal of which are at La Boca, at Matachin, and at Colon. These shops contain a considerable quantity of usable machinery. They were put into service during the summer and autumn of 1904, and have since been somewhat enlarged and developed. They constitute a valuable asset, and will be of great service in repairing machinery, rolling stock, and other appliances required in the work of construction of the canal, and they have sufficient capacity for the purpose of building some of the simpler forms of plant required in the work.

NEW FIELD WORK.

The Board has had access to all the data on file in the office of the Isthmian Canal Commission. Very accurate cross sections of the canal prism included between Obispo and Paraiso, seven miles and a half, were obtained. These cross sections were taken at very close intervals where the slopes are changing; in those portions where the grade is nearly uniform and the topography unmarked by notable features the cross sections are considerably farther apart. These cross sections are used in the estimates of the Board.

It early became apparent that additional information was desirable relating particularly to the possible dam and lock sites at Mindi, Gatun, and in the vicinity of La Boca. The Board requested the Isthmian Canal Commission to have further examinations made, as follows:

1. On the Mindi line the examination to be topographic with respect to the ridge line to the east of the Mindi through to Jaramillo Hill, thence to the shores of Limon Bay, in order to develop any low passes communicating with the Chagres River, and over the Jaramillo Hill near the high ridge line to the Chagres River and across the same, connecting with the high land to the west of the Chagres. This examination to be carried up to elevation 50.

2. Borings and topography at Gatun, south and west from Gatun Hill, over the hill opposite, across the diversion channel, and to high land beyond. Also to develop lock foundations in the hill east of Gatun.

3. A survey showing the necessary relocation of the Panama Railroad in case of a terminal lake formed by a high dam at Gatun.

4. A line of soundings across the Rio Grande Valley from Sosa Hill, passing by La Boca pier, to the high land above the mouth of the Farfan River.

5. A survey and soundings on the shortest line from Ancon Hill across the high land to the east, to show the physical conditions that would influence the construction of a dam to raise the water in the Rio Grande Lake to elevation of about 65.

6. Borings to rock on saddle between Ancon and Sosa hills, and across the Rio Grande from Sosa Hill to the nearest high land, to develop the practicability of a lock between Ancon and Sosa and a dam for raising water 30 feet above sea level. Also borings along a line for the proposed Pacific section of the canal, this line leaving the old route about kilometer 63, passing straight to the saddle between Ancon and Sosa hills, thence in a straight line to deep water in the bay to or near the entrance channel now in use.

With reference to the Mindi location Mr. F. B. Maltby, division engineer, reported:

> On the west sideof the canal the high ground is continuous from the Jaramillo Hill to the Chagres River. * * * From a personal examination I am quite sure that a point can be found in this vicinity where the distance across the Chagres Valley to an elevation of at least 50 feet is not more than 3,000 feet. I think it more than probable that surveys would develop a possible crossing of a shorter length. On the east side of the diversion at Mindi the hills are simply isolated knolls for a distance of half a mile east from the diversion channel. From these there is a continuous ridge which is very much broken in elevation, but in which there is no point which has an elevation of less than about 40 feet. * * * It therefore seems possible that, should such a project be contemplated, a dam might be built from the Jaramillo Hill across the canal connecting the various hills as far as the east diversion opposite Mindi. From there for a distance of half a mile it is probable that a dam having a base at an elevation of only five or six feet above the sea would require construction for half the distance. In addition to this there would be a dam across the Chagres River of about 3,000 feet in length.

In response to the request of the Board, some topographic work was done in the vicinity of Gatun, outside of the limits of the French maps. Borings were taken across the valleys along the lines indicated, and this information was forwarded for consideration of the Board. The topography and the location of the borings are shown on Plate XI, and the section as determined by these borings on Plate XII. These borings were completed across the entire valley and taken at intervals along the surface of the ground up to an elevation of about 85 feet at each end. It is noted that the elevation of the indurated clay follows very closely the irregularities in the surface of the ground. The borings were also made on the hill to the east of the Chagres for the purpose of determining a site for a lock, and this same condition generally holds, the clay being found between 15 and 20 feet below the surface of the ground.

Mr. Stevens reports, with reference to the Gatun site:

> Extreme depth, to so-called rock or indurated clay, was found in the valley at 258 feet below mean tide level and on the bank of the west diversion. Apparently there are two deep and distinct valleys or gorges in this material, with the indurated clay rising a considerable distance above the mean low tide between them. A flow of water was reached in several of these holes. Most notable ones were at station 54+51 and at station 52+67. The flow of water at the former was quite a strong one, and indicated emphatically the imperviousness of the soil overlying the gravel.

See section, Plate XII.

The borings in the vicinity of La Boca and Ancon Hill, as well as those of the marine section, are given on Plate VII. They show the practicability of a lock in the Ancon-Sosa saddle and also at the westerly foot of Sosa Hill.

The geological sections also show depths to rock at several points that have been suggested as suitable for dams required in maintaining a terminal lake in the Rio Grande Valley.

The Commission and its engineering staff responded with great promptness to every request made upon it for additional physical data.

PROJECTS OF MR. LINDON W. BATES.

Mr. Bates presents three projects, designated A, B, and B′. He does not appear to attach great importance to the elevations of the lake surfaces shown in those projects, as the latter, including the elevation of the summit levels and terminal lake levels, where those features are found, are modified to almost any extent under his general presentation.

The feature of terminal lakes is not new, indeed it is as old as the International Scientific Congress at Paris in 1879, one of the many plans proposed at that time suggesting a dam at Gatun. Again, in 1880 Mr. C. D. Ward, member of the American Society of Civil Engineers, advocated the creation of a reservoir formed by a dam at Gatun for the purpose of securing interior lake navigation. Nearly two years ago he again agitated the same question in communications to members of the then Isthmian Canal Commission, and published a paper upon the same subject in the Transactions of the American Society of Civil Engineers for May, 1904. (See Appendix I.)

Mr. Bates appears to express a preference for project B, which contemplates two terminal lakes, one on the Caribbean side formed by a dam at Mindi called Lake Chagres having a maximum elevation of water surface of 33.5 feet above mean tide, another at the Panama end formed by a dam connecting Ancon and Sosa hills with each other, and a second dam from Sosa Hill to the high ground on the westerly side of the Rio Grande estuary. A third dam would also be needed to prevent escape of water over low land east of Panama, the waters thus impounded to be called Lake Panama, with a maximum elevation of water surface of 27 feet above mean tide. He also has an intermediate lake formed by a dam across the Chagres at Bohio called Lake Bohio, with the summit level at a maximum elevation of 62 feet extending through the continental divide to Pedro Miguel.

This plan provides four lockages—one at Mindi, one at Bohio, one at Pedro Miguel, and another between Ancon and Sosa hills. A variant of the plan contemplates the removal from Bohio to Gatun of the dam forming the intermediate lake or summit level.

This project also includes two terminal harbors, one called Balboa, a small protected area formed behind a proposed breakwater from the easterly side of the southerly portion of Limon Bay consisting of two parts, the opening between forming the entrance for the deep approach channel from deep water outside to the entrance of the canal proper, which he locates at the mouth of the Mindi.

Another possible variant of this plan is indicated by placing a breakwater in two parts directly across Limon Bay from Manzanillo Point to Toro Point, with an entrance between them about 1,000 feet wide, but in the hearing before the Board Mr. Bates stated that he did not consider this breakwater necessary, and its cost is not included in his estimate of cost. (Project B.) For the reasons already stated in the section on harbors in this report it is the judgment of this Board that the outer harbor, through which the dredged approach channel lies, must be protected practically from the point of its beginning in deep water to the southerly limit of Limon Bay. This may in a measure be done by the outer breakwater shown on Mr. Bates's plan, in which case the inner one could be omitted. In making up the estimate of cost of this project the additional cost of this breakwater should therefore be included.

The general project of the harbor of Panama, forming the Pacific terminus, is much more elaborate than the harbor of Balboa. The former is to be inclosed by two great breakwaters, one starting at Guinea Point and running in a southeasterly direction to the island of Naos, and the other starting at Paitilla Point, extending first nearly due south, then southwesterly to the island of Perico. He proposes to dredge an entrance channel to the canal between the islands of Perico and Naos and running straight to the lock in the dam between Sosa and Ancon hills, the canal line nearly to Miraflores constituting a straight extension of the center line of the approach channel. This harbor is an ambitious one and includes a naval station on the north side of Ancon Hill. An entirely new site, formed by filling with the excavated material from the canal, is proposed for an extension of the city of Panama many times in extent the area occupied by the present city. He proposes some minor modifications of these projects for new harbors, but they do not affect materially the character of his harbor plans. These proposed terminal harbors are common to his three canal projects.

Project A has a summit level of 27 feet only above mean tide, maintained by two dams, one at Mindi and one connecting Ancon and Sosa hills with the high ground above Farfan Point, both of these being identical with the terminal dams of project B in location, but the former is of less height. The peculiarity of this plan is the low summit level, 27 feet above mean tide,

extending from Mindi through to the Panama terminus, a single lift lock being placed at Mindi and another in the Ancon-Sosa saddle.

The remaining project, B′, bears approximately the same relation to project B that B does to project A. As B is derived from A by inserting an intermediate lock and summit level between the terminal lakes, so B′ may be said to be derived from B by raising the summit level, introducing an intermediate lake between the Caribbean terminal lake and this level, and providing a second lock at Pedro Miguel. This project, therefore, contemplates two terminal lake levels formed by dams at Mindi and at Sosa Hill, already described in project A, with the elevation of water surface behind those dams 27 feet above mean tide; a dam at Gatun, behind which the elevation of water surface is brought up to 62, and finally a summit lake held by a dam at Bohio forming the summit elevation at 97 feet above mean tide, retained at the Pacific end by a dam and flight of two locks at Pedro Miguel. There are thus found six locks in this project, one at Mindi, one at Gatun, one at Bohio, a flight of two at Pedro Miguel, and one at the Ancon-Sosa saddle, it being understood that duplicate locks are contemplated throughout.

After a comprehensive examination and study of these various projects the Board was unanimously of the opinion that if project A alone were to be considered it could not be preferred to a sea-level plan. The low elevation of its summit brings the volume of excavation so near to that necessary for a sea-level plan that the work required, combined with that involved in the construction of the two dams and the locks, possesses no economical advantages over that required for the canal at sea level. The Board, therefore, unanimously disapproves project A.

This disapproval leaves projects B and B′ only to be considered. As Mr. Bates himself indicates a preference for project B, the Board has centered on it the greater part of the consideration given to these two plans. The Board is unanimously of the opinion that the summit level of 97 feet above mean tide of project B′ should not receive approval.

The papers, including plans and other information first submitted by Mr. Bates, did not include a detailed statement of the amounts of work required to be done or of the items of cost of the different classes of work included. Upon request of the Board, however, Mr. Bates submitted supplementary profiles and sections of prism of the three projects or parts of those projects, with a tabulation of approximate quantities of excavation required under the three different plans. These approximate quantities were not given in sufficient detail to enable the totals to be satisfactorily checked or confirmed, nor were those approximate quantities so classified as to exhibit the amounts of hard and soft material required to be excavated or the amounts of the different classes of work to be performed for the appurtenant structures such as locks, dams, and other main features. It has, therefore, been impracticable to verify the lump or partially detailed estimates of cost set forth in the papers and plans submitted by Mr. Bates. Under such circumstances it is impossible to deduce close approximate quantities of work required to be performed in the execution of the plans, or a reasonably close estimate of cost of the entire work or of its various parts. The Board has made as close a comparison as possible between the total itemized quantities of excavation submitted by Mr. Bates and the more or less corresponding quantities computed by the Board for its own purposes. It has further coordinated for use in estimating the cost of the work under plan B its own estimates of costs for such appurtenant works as locks, dams, breakwaters, and other similar main features of the canal project.

The items of excavation given in his supplementary "Graphic diagram of approximate quantities" appear to be less than those which the Board would estimate for the same purpose, but if the unit prices adopted by the Board be applied to the quantities for project B as given by Mr. Bates, the total cost of excavation alone, after deducting the useful French work, will be $85,289,500. To this sum is to be added the estimated costs of the dams and locks at Mindi, Gatun or Bohio, Pedro Miguel, near Panama, Ancon-Sosa, La Boca, and other large features of the plan, besides the breakwaters and other works at the two terminal harbors, and the regulating dams at Gamboa and other points on the Chagres, as indicated in his plans. His allowances for these various main portions of the work other than excavation seem to be insufficient. If these

works be allowed for on the same basis as corresponding works in the Board's plans the total cost of the entire project B, without adding any percentage for contingencies or other allowances, will approximate about $160,000,000. To this must be added a large but indeterminate sum for the great extent of country flooded by the terminal lakes, particularly Lake Chagres or Lake Bohio if Gatun rather than Bohio be adopted for the location of the dam creating the summit-level lake. This inundated land includes a large portion of the most valuable lands in the Canal Zone and its near vicinity. It would include many villages along the line of the railroad between Mindi and La Boca, besides lands devoted to grazing and dairy purposes as well as many banana plantations. It is quite impossible at this time to estimate the damages which the United States Government would have to pay for these submerged lands, but if past experiences in this field are any guide in making this estimate the sum would be very large. This question is also complicated by the doubtful validity of titles of many parcels of land claimed to be owned by private parties.

The land damages alluded to do not cover the lands which would be required for the regulating lakes at Gamboa and above that point on the Chagres River. While compensation would have to be made for these damages, that district is comparatively uninhabited and the amount of compensation would be relatively small; but this is an outlay practically common to all projects in which the control of the Chagres is to be effected at Gamboa or at points above.

The extended examination which the Board has given to Mr. Bates's project B fails to indicate that the work embraced by it can be completed for a sum much less than an amount nearly 50 per cent in excess of his estimate of $134,000,000, including the additional cost for the outer breakwater in Limon Bay and the same 20 per cent for contingencies, sanitation, and policing used in the other estimates of this Board. There can, therefore, be no material economy in the adoption of this plan.

At Obispo, where the Chagres cuts the canal line, Mr. Bates introduces a feature which he calls the Obispo triangle, designed to divide the flood waters of the Chagres entering the canal into two equal portions, one to flow through the canal prism toward Panama and the other toward Colon. The accomplishment of this result is practically an impossibility.

The assumption is unwarrantable that a large volume of water introduced at the middle point of a channel over 20 miles long, which in the dry season is an ordinary canal and which in the rainy season receives lateral contributions varying with the locus of local downpour, will automatically divide itself into two equal volumes flowing in opposite directions.

Water levels will determine the flow at the central point, and local deposits with erosions caused by the excessive discharges will completely destroy the conditions necessary for the equal and opposite flows which he assumes.

That some of the waters, the quantity to be determined by experience, would seek exit to the south through the canal prism is probable, and the sea-level plan contemplates such a southern diversion, but it is not claimed that it would be automatic and equal. As the distance to the Pacific is less than to the Caribbean the hydraulic gradient will be steeper, and the flow in the sea-level canal would be controlled by the regulating sluices proposed; but the diversion of any part of the Chagres flow to the Pacific is not an essential feature of said plan.

Furthermore the Board believes that the proposed method of control of the Chagres, by a number of small reservoirs at Gamboa and above that point on the river, will be less effective and more expensive to maintain than that resulting from the construction of a single larger reservoir with a suitable dam at Gamboa. It is the further judgment of the Board that the proposed designs for the dams, dikes, or barrages proposed to be constructed at La Boca, Mindi, Gatun, or Bohio do not show the incorporation of such features of construction as will give reasonable assurance of their stability or efficiency for the purposes contemplated, and that a proper provision for those features would greatly swell the costs indicated by Mr. Bates.

Again, Mr. Bates has outlined no method and has apparently given no consideration to such procedures as would be required to transform the work executed under his project B to a sea-level canal, nor has he made any estimates of cost whatever for such transformation. It is

obvious, however, that the work of transformation would be very costly and that the expense of that work would swell to an excessive or even prohibitory amount the ultimate cost of the sea-level canal so attained.

This project is less well adapted for transformation to a sea-level canal than the lock plan with a summit elevation of 60 feet above mean tide adopted by the Board for comparison, although the difference between the two is not great. Such difference as exists is found chiefly in the more costly structures of Mr. Bates's project, such as the dam and spillway at Pedro Miguel and the works at the Obispo triangle, and in the less effective system of control of the Chagres floods. Much more elaborate harbor constructions and the more costly character of their appurtenant works chiefly account for the excess of the estimated cost of Mr. Bates's project B over that of the 60-foot summit level lock plan of the Board, to which allusion has already been made.

Finally, this Board believes that on the grounds of both first and ultimate economy, for safety in construction and operation, and in adaptability for transformation to a sea-level plan, the lock plan above referred to, adopted by the Board for purposes of comparison, is to be preferred to Mr. Bates's project B.

It has been urged by Mr. Bates that the health conditions would be much improved if the plan he proposes should be adopted of submerging the valleys of the Chagres and Rio Grande and converting those broad areas into fresh-water lakes. It is now the generally accepted theory of sanitarians that the mosquito which causes yellow fever breeds only in vessels and pools of fresh water in the houses and in their immediate proximity. If this is accepted as fact we should not expect that the existence or nonexistence of broad expanses of fresh water would have any influence upon the occurrence and spread of yellow fever. In the margins of lakes and ponds the malaria mosquito would breed, and on the other hand the submergence of the sites of present villages would deeply flood and destroy the present habitat of the anopheles, but they would find new breeding places in the shallow margins of the lakes; since these lakes could not be formed until the canal is completed, the health conditions as affected by the malaria mosquito would not be changed during construction. If the sea-level plan be accepted, the ultimate drainage will be far below the earth's surface nearly throughout, and the desiccation of stagnant pools and marshy surfaces near the canal will be easy. There will be no lake margins near, and the canal will at all times be the ultimate receptacle of all surface drainage and will contain only clear water flowing through a channel with steep sides, which water will, near the termini, be salt or brackish and in the dry season salt throughout. All things considered, it is not probable that the conditions as respects malaria would be materially different whichever be the plan adopted; but if there is a difference, the sea-level waterway will be more favorable to health conditions.

That the Isthmus would continue to be pest ridden unless the transit be effected through submerged valleys is rejected by the Board as without any basis of sound argument or fact. The present transit of the Isthmus, which, with voluntary and necessary detentions usually occupies at least a day, has not, so far as disclosed, for a quarter of a century been attended with jeopardy to health, and under no conceivable conditions of transit by ocean steamers is it believed that serious dangers would be incurred by the passengers and crews of the vessels. The health of the marine battalion that has been serving on the Isthmus for two years has been uniformly good. No member of the command has contracted yellow fever and there has been no death from malaria.

For all the above reasons the Board disapproves the adoption of project B of Mr. Bates's system for the construction of the Panama Canal.

PLAN OF MR. P. BUNAU-VARILLA.

Mr. Bunau-Varilla proposes to construct a lock canal with a high summit level, and after its completion to proceed with its transformation into a sea-level canal. He estimates the time required to complete the lock canal at four years, with a summit level at elevation 130. The

transformation will require a widening as well as a deepening of all channels above sea level. The widening above water is to be done first by the ordinary methods for excavation in the dry, but all excavation below water is to be by dredging. By using water power to develop electricity for the dredges and other machinery he estimates that the work can be done at a very low cost.

In a succeeding section the Board has indicated its judgment that any lock canal may be transformed in some manner into a sea-level canal, so that, if time, cost, and danger be left out of consideration, the change can be made without sensible interference with traffic. If the latter condition were observed rigidly the time and cost would be greatly increased, and it is probable, in order to avoid such extraordinary increase, that some interference with traffic would be tolerated in the process of transformation, as in many canals or navigated waterways the depths and widths of which have been increased.

Mr. Bunau-Varilla has outlined to the Board a very ingenious procedure to be followed in effecting such a transformation, with special reference to the difficulties of eliminating the locks successively and of disposing of the excavated materials. If the locks were of single lifts (as would be the case in the lock-canal project with summit level at elevation 60), he would modify their construction by placing the gate sills for the upper ends of locks at the level of the canal bottom below instead of above the lock, the latter being the usual practice. This would result in adding greatly to the weight of these gates, making them a little less convenient to operate. With locks so arranged the canal above the lock could be deepened in moderate stages, of five to ten feet for example, during which process the full depth of 40 feet of water would be maintained in the canal and no excavation would be required in depths exceeding 45 or 50 feet. After this amount of deepening throughout the summit level the water would be lowered by the same amount and the process repeated sufficiently to depress this level to those adjacent, when all the gates in the upper level could be thrown open. Before any further lowering could be commenced it would be necessary to remove the floors of the duplicate locks, one lock at a time, while open navigation would be maintained through the other.

If the locks were in flights of two or more, the modification in the original construction would not be so simple; in each lock below the upper one an additional pair of gates would be placed near the upper end, so that when the gates and floor of the upper lock were all removed and the site deepened the additional pair could be used as upper gates. Until the completion of the change the provision of additional gates would lengthen the locks about 100 feet, and thus increase the time required for filling and emptying and encroach on the water supply. The process of transforming the canal would be the same as for a canal with single locks up to the point when the gates of the upper lock are thrown open after the level above has been lowered by an amount equal to the lift of that lock. The transformation would then become more difficult, because if one lock were closed to remove the floor there would be lock navigation instead of open navigation through the other one, and if the traffic were heavy it might be necessary to build a third flight so as to have two in constant use; and the provision of a third flight might be demanded for the security of the navigation so that duplicates might always be in readiness, except during short periods when one was being repaired or the machinery refitted. It seems probable that it would be judicious to provide the third flight of locks before beginning the transformation, and if this were done any desired change could be made in the same by successively closing them to navigation until the changes were made, and with such third flight the modifications suggested by Mr. Bunau-Varilla, which would be objectionable in a lock canal, would be dispensed with.

For disposing of materials excavated during the transformation Mr. Bunau-Varilla proposes to construct a flight of locks which would connect the elevation of sea level with the surface of Lake Gamboa, and use this lake as a dumping ground for materials dredged from the canal. Such of these locks as were below the surface of the summit level of the lock canal would have to be built before any raising of the water in the Chagres, and all would have to be built before beginning the transformation. The lower locks would be submerged, and would not be used until they emerged with the successive lowering of the summit level. With this communication

with Lake Gamboa it would not be necessary at any time to pass barges loaded with excavated materials through the canal locks, and interference at the locks with navigation would be entirely avoided.

This method of disposing of dredged material is feasible but not inexpensive, and although the disposal of a large volume in Lake Gamboa would reduce to some extent its efficiency for flood control and for catching silt, the volume of the lake would be so great that this reduction would not be important. If a lock-canal project with a small terminal lake on the Atlantic side should be adopted, alternatives to the plan of disposal submitted by Mr. Bunau-Varilla would be to pass the barges with excavated material through the canal locks to sea, from which some interference with navigation might result, or to rehandle the greater part of the dredged material at various points along the canal and deposit it on the areas above water level, which would be expensive. With summit level at elevation 85, extending northward to Gatun, a vast amount of excavated material could be dumped in the low areas in Lake Gatun above Bohio until the summit level were lowered to about elevation 60, and between Bohio and Gatun until the summit level were lowered to about elevation 30. Of the relatively small amount of material then remaining, the portion suitable for suction dredging could be pumped to higher elevations and the remainder could be passed through the canal locks to sea without very serious or prolonged interference with navigation; or, if this limited interference were found inadmissible, it could be transferred from barges to cars and disposed of at some suitable dumping ground. Although the unit cost of such rehandling would be considerable, the volume would be small compared with the amount to be disposed of in a similar manner if the 60-foot level were adopted for the summit and the 30-foot level for the stretch between Bohio and Gatun.

The claim made by Mr. Bunau-Varilla that the excavation required for the transformation can be done at low cost rests mainly on the expectation that by the use of electric power, developed at the Gamboa dam and distributed along the line, the expense for fuel for generating steam will be eliminated and the cost of all mechanical operations reduced by what appears to the Board to be a much exaggerated estimate of the economies thus effected, and on the further expectation that excavation can be made at very much less cost by dredging than in the dry. This reduced cost of dredging is probably true for sand, clay, or other materials that can be moved without being shattered by some preliminary process, but nearly all the materials to be dredged for the transformation are classified in the Board's estimates as rock, and will have to be loosened by blasting under water, by breaking or pulverizing, as in the Lobnitz method, or by such other methods as may be devised. Moreover, it must be remembered that the greater part of the dredging is to be done under 40 to 50 feet of water, which will add much to the cost. The unit prices adopted by the Board represent its best judgment in regard to the cost of excavating the several classes of materials which the transformation would require with the best methods and appliances now in use. Comparison of the cost of first constructing a lock canal and then lowering it to sea level with the cost of making the latter canal at once, on the basis of adopted unit prices, shows that the removal of nearly all the material under water by subaqueous blasting or otherwise shattering, and then dredging, would cost much more than if taken out in the dry; and hence, as is shown in a following section of this report, the final cost of a sea-level canal ultimately secured by the process of transformation, and of the channel dimensions adopted, would be about $100,000,000 greater than by immediate construction, without taking into account the loss of the costly locks and other structures abandoned or demolished after reduction to sea level.

The advantages claimed to be secured by Mr. Bunau-Varilla by his method of excavation of successive strata without occupation of the navigation channel would be realized only when the side slopes are not steep, the advantages increasing with gentle slopes and disappearing as the slopes become more nearly vertical. Inasmuch as by far the greater part of the under-water excavation in his process of transformation would be made in material classed as rock, large portions of the side slopes might be as steep as four vertical on one horizontal, and a very small portion, if any of them, will be less steep than three vertical on two horizontal. It is therefore probable that little would be gained through this special feature of Mr. Bunau-Varilla's plan.

While it is possible that the actual cost might be lessened by improvements in means and methods yet to be developed, it would not be prudent to assume this and reduce the estimate given above.

Mr. Bunau-Varilla estimates the time required to build a high-level lock canal at four years. Although smaller locks than those proposed by the Board or those required by the act of Congress under which the canal construction has been commenced might be defended for a canal built for temporary purposes, they would have to accommodate war ships of the largest size as well as large commercial ships, and could not be made as small as those proposed by the New Panama Canal Company, which were to be 82 feet wide with a useful length of 738 feet. The Comité Technique estimated that the construction of the Bohio locks would require four years after the excavation was practically completed, and no shorter period has been suggested by any later commission. Mr. Bunau-Varilla's project not only provides more locks along the canal line than any other plan, but also requires the construction, as part of the original work, of those locks of the flight leading from sea level to Lake Gamboa which are founded below the summit level of his plan. Making due allowance of time to provide suitable excavating plant and to make the excavations at the several lock sites, the term of four years is far too short for the work to be done.

After a full and careful consideration of all the features of Mr. Bunau-Varilla's plan, the Board is of the opinion that it should not be adopted for the Panama Canal for the following reasons, which have already been indicated:

1. The construction of the large locks required under the present law and necessary for the accommodation of the traffic seeking the canal after its completion makes it quite impossible to complete the preliminary lock canal even nearly within the period stated.

2. The excessive cost of transformation added to the loss of costly locks and other appurtenant structures required by the preliminary lock canal.

3. If the lock canal is likely to be retained for many years it should be made for the most efficient service and not be encumbered with modifications in lock construction which would prove inconvenient in use.

PLAN OF THE ISTHMIAN CANAL COMMISSION, 1901.

This plan was submitted to the Board and has received careful consideration. The plan as described in detail in the reports of the Commission is here referred to only as respects certain features.

The depth proposed for the excavated channel was 35 feet and the bottom width 150 feet, except in Colon Harbor where 500 feet was proposed, in Panama Bay 200 feet, and in submerged excavated channels in Lake Bohio 200 feet. The summit level was to be at a maximum of 90 feet, attained by two locks on the Atlantic side at Bohio, and on the Pacific side by one at Miraflores and two at Pedro Miguel. The locks were to have a clear length of 740 feet and width of 84 feet. An earth dam with masonry core wall at Bohio was to form a lake in the Chagres Valley above that point, with elevation of surface varying from 82 to 90 feet. The alignment was the same as that of the French lock plan. The entrance to the canal at Colon required a double curvature, the radius of one of the curves being 3,281 feet. The total cube of excavation was estimated at 94,863,703 cubic yards; the cost, with 20 per cent for contingencies, was fixed at $144,233,358, and the time of completion ten years.

As stated in another part of this report, the Spooner Act authorized the construction of an isthmian canal and fixed certain conditions respecting dimensions and capacity which were not within the cognizance of those who recommended the plan of 1901. If the canal then contemplated were now in existence it would not afford passage to the largest ships now in course of construction.

The plan contemplated five lift locks—works which the Board believes should not be used if a convenient and safe passage is to be provided for the largest existing and expected vessels at a cost in time and money which is reasonable; the plan under consideration would not fulfill present and future requirements.

The Board has therefore found itself unable to recommend the Isthmian Commission's plan of 1901 for adoption by the Government, nor does it believe that any modification of that plan involving the use of lift locks should be adopted for the Panama Canal.

PLAN OF MAJ. CASSIUS E. GILLETTE, U. S. ARMY.

Among the papers submitted to the Board was an article by Maj. Cassius E. Gillette, Corps of Engineers, U. S. Army, which had been printed in the Engineering News of July 27, 1905. The article is entitled "The Panama Canal: Some serious objections to the sea-level plan." Under this heading occurs a general description of the various canal plans, ending with a description and recommendation by the author of a plan for a 100-foot summit level canal.

He states that the engineering work is best which accomplishes the desired object at the least expense, and also that the cost of a canal is made up of the first cost, with that of operation and maintenance, and the cost of enlargement, the latter being a very important matter, as is shown by the history of all existing canals. Mention is made of the work being done on existing canals at the present time, and, in the opinion of the author, the best canal would be one that could be most easily enlarged. He thinks that the lock canal can be more easily changed and its capacity increased.

He points out the advantages to be obtained by a canal with a high dam at Gatun, with reference to the elements of cost, time of construction, serviceableness, and ease of enlargement.

In his opinion the question of sediment has not been heretofore sufficiently considered, and a description of the topographical features of the country as affecting sediment in the streams is given. The problem of disposing of sediment with a sea-level canal is, in the author's opinion, a serious one.

It is alleged that large ships would have difficulty in navigating the present Atlantic entrance in the high winds which prevail in that vicinity, on account of the sharp reverse curve necessary to enter the canal. He recommends practically a straight line for the canal from Gatun to deep water in Limon Bay, almost exactly the line which has been recommended by the Board in the sea-level plan.

Objection is made to a high earth dam with a masonry core at Gamboa. He suggests that a masonry core really converts a dam from an earth and rock structure into an inefficient masonry work, and that by the stoppage of all seepage water the rock and clay above the dam become thoroughly saturated, and the large proportion of soluble clay in its composition would make it, so far as pressure is concerned, heavier than water and increase the thrust.

Major Gillette advocates a 100-foot summit level canal with a dam at Gatun. This will provide, in his opinion, a lake having an area of at least 100 square miles, subject to very slight fluctuations, and capable of settling for ages all the mud that the streams would bring into it; it would also supply all the water necessary for lockages and would give a straight channel between Bohio and Gatun.

The proposed dam at Gatun is of earth, with a core of impervious material. To prevent seepage under the dam a method is suggested of using steel sheet piles driven to a depth of about 60 feet, and then to drive, in sections to bed rock immediately alongside of this sheeting, three-inch pipes, five to six feet apart, through which is to be forced cement grout.

The project under discussion assumes a flight of three locks whose usable dimensions are 900 feet in length by 90 feet in width, with lifts of 35, 35, and 30 feet. The author thinks the prejudice against locks of greater lifts than 35 feet, based upon difficulties inherent to gates with miter sills, may be overcome by the use of floating caisson gates. The estimate for the flight of locks at Gatun is $4,900,000. It is evident that this is for a single flight of locks.

Many of the criticisms of the various suggested canal plans are the same which have been made in the sessions of the Board, whose plan is the logical development as a correction of the defects of previous plans. The Board has adopted a line for the canal from Gatun to deep water which is practically the one recommended by Major Gillette.

His criticism of a high earth dam with a masonry core at Gamboa is worthy of attention. This matter has been considered by the Board, and in its plans the proposed estimate

of the Gamboa dam has been made large enough for the construction of a dam of masonry throughout.

The dimensions of the Gatun dam are very similar to those recommended by several members of the Board in its discussion, for example, of the 85-foot summit level plan. His estimate of cost, however, appears to be too small. The Lock-Canal Committee of the Board estimated for a dam at Gatun for a lake level of this height, with its spillway and regulating works but without any arrangements to stop seepage under the dam, a total of $8,000,000. Major Gillette, for his 100-foot summit level, estimates $2,800,000. It is probable that one cause of this discrepancy is the fact that the Board has had the advantage of recent surveys, which show that the maps from which Major Gillette worked were inaccurate.

The objection to a dam at this site has already been set forth in the discussion on dams.

The Board is unable to approve the suggested method of preventing seepage under this dam on account of its cost and doubt as to its effectiveness as applied to that site.

The Lock-Canal Committee of the Board, in its estimate for the 85-foot summit level with flights of three locks each, having less lift but somewhat greater length and width, viz, 1,000 by 100 feet, arrived at the sum of $7,410,000 for each flight. It is very evident to the Board that the estimates of cost given by Major Gillette throughout his paper are very much too small.

THE 60-FOOT SUMMIT LEVEL PROJECT ADOPTED FOR COMPARISON WITH THE SEA-LEVEL PROJECT.

This plan provides for a summit level of moderate height and for corresponding dams. Such a canal could be built in somewhat less time than one at sea level. It would have duplicate locks throughout of one lift only between adjacent levels, and could be transformed into a sea-level canal with less difficulty than one with a higher summit level. For these reasons it is preferred by the Board to any other lock-canal project before it.

The proposed harbor on the Atlantic side is to be the same as described in the sea-level plan. The canal between Mindi and Gatun is to be 500 feet wide, as in the harbor, giving a broad waterway and furnishing material for an earth dam at Gatun of sufficient height to sustain a head of 30 feet. The lift at Gatun will be made with one lock. From Gatun to Bohio the channel is to be 300 feet wide, the banks generally submerged. At Bohio another dam and a lock of the same lift as at Gatun would raise the level to elevation 60. Sluices for the discharge of surplus water are provided in connection with both dams.

For the control of the floods of the Chagres and the storage of water for canal supply a dam is proposed at Gamboa identical with that for the sea-level canal. From Bohio to San Pablo, about eight and four-fifths miles, the canal is to be 500 feet wide, with channel banks generally submerged; from San Pablo to Obispo, nearly seven miles, it is to be 300 feet wide, and at the latter place reduced to 200 feet, which is to be continued for a distance of seven and one-half miles through the Culebra cut to Pedro Miguel.

The descent to the Pacific is to be made by two locks, one being at Pedro Miguel, the other six miles beyond, on the west side of Sosa Hill, near the shore of Panama Bay. The canal is to be 300 feet wide between these locks with water surface at elevation 27, the lift at Pedro Miguel being 33 feet, that at Sosa varying with the tide, being about 34 feet at ordinary low water. A spillway to discharge surplus water is proposed at the Ancon-Sosa saddle. The level between Pedro Miguel and Sosa is to be maintained by an earth embankment of considerable dimensions across the Rio Grande opposite Sosa Hill, and smaller ones in the Ancon-Sosa saddle and between the Ancon Hill and high ground to the eastward. These embankments, as well as the Gatun and Bohio dams, are to have unusual width and height above water.

In Panama Bay a short distance beyond the Sosa lock the line joins the line of the French company, and the width of 300 feet is maintained from the Sosa lock to the seven-fathom contour. The location of the canal is the same as that of the sea-level canal except a small variation at Gatun and the greater one from Pedro Miguel to the terminus in Panama Bay resulting from locating the tidal lock on the west side of Sosa instead of in the Ancon-Sosa saddle. In the narrow channel through the Culebra cut the sides of the wet section are to be vertical or nearly so; elsewhere they have slopes suitable for the material passed through. The widths above

given are bottom widths. Excluding the locks, only one-sixth of the canal is to have a bottom width of less than 300 feet. (See Plate IV, Maps and Diagrams.) It is estimated by the Board that the cost of the canal thus described, including 20 per cent for contingencies, would be $176,000,000.

SAFETY AND PROTECTION.

The general question of defense of the Isthmian transit will be in no way affected by the type of the canal.

Dismissing, then, any consideration of the question of general military defense, the Board is of the opinion that the safety and protection of the canal will be sensibly influenced and affected by its type; in estimating these influences the following considerations should be noted:

As having very important bearing upon the type of canal to be recommended for adoption, it is assumed to be of primal importance in the design of the waterway that the military necessity of the United States demands a passage between the two oceans, whereby the navy in the Pacific might be quickly transferred to the Atlantic, and vice versa; which necessity, in 1898, became so important that it had a controlling influence upon public opinion respecting the canal and had a decided influence in crystallizing ideas and in hastening final action by Congress on the whole project for interoceanic communication.

In the Spooner Act of June 28, 1902, already quoted in part, is found the only Congressional legislative requirement respecting the dimensions and protection of the canal. In that act it is provided that the canal must afford a passage for the largest existing vessels as well as for those which may be reasonably anticipated, and that this passage must be a "convenient" one, so that all "necessities" of shipping may be met. Necessary measures must be taken to insure safety and protection. The harbors to be provided must be "safe and commodious" for said existing largest vessels and for those to be expected in the future. It therefore behooves the Board to show that the type of canal recommended for adoption possesses the features best subserving adequacy in capacity, convenience and safety in use, and capability for protection.

According to Sir W. Laird Clowes's Naval Pocket Book for 1904, the largest war vessel afloat in March, 1904, had a length of 454 feet. The greatest beam noted is of 80 feet, and the deepest draft 27 feet 2 inches. However, several battle ships and cruisers are building of from 14,000 to 20,000 gross tons, and at least one of 22,000 tons, but the authority consulted does not give particulars as to size of this last, although war ships of such tonnage may well have dimensions closely approximating those of the largest existing commercial vessels. The largest war vessel building of which particulars are available has a beam of 83 feet 6 inches, but as yet there is no indication that the commercial and passenger steamers will not continue to lead in size, and therefore it results that if the channels, anchorages, and locks are adequate for the largest ocean liners and freighters, then the largest naval vessels will find adequate dimensions for convenient passage.

The beam of modern seagoing vessels furnishes a fair indication of tonnage and other dimensions. By reference to Lloyd's Register of Shipping, 1905–6, and the before-cited Naval Pocket Book, it is seen that as respects beam the large commercial and war vessels may be classed as follows:

Beam of large ocean steamers.

Beam.	Commercial ships in use.	War ships in use or projected.	Total.
40 to 45 feet	2,101	201	2,302
45 to 50 feet	1,993	139	2,132
50 to 55 feet	692	110	802
55 to 60 feet	177	83	260
60 to 65 feet	53	44	97
65 to 70 feet	26	123	149
70 to 75 feet	6	85	91
75 to 80 feet	3	81	84
80 to 85 feet	.....	8	8
Total	5,051	874	5,925

The largest commercial steamers recently put in service are generally of less breadth than the newest naval vessels, but the former are of greater length. However, the Cunard Company has now under construction two steamers 800 feet in length and 88 feet in beam.

It has been urged in some quarters that the express passenger steamers will not make commercial use of the canal. If this contention be admitted as true, it does not follow that the capacity of the canal should be restricted as to dimensions, so shutting out this class of the ocean marine. It is understood that the requirement imposed by the statute that the canal must conveniently accommodate the largest existing and expected ships contemplated, in the opinion of the law-making power, the existence of a necessity for such dimensions which would arise in the event that the military needs of the United States may require the transfer from one ocean to the other of large bodies of troops with their equipment and supplies. In such contingency the largest express steamers obtainable would certainly be employed as transports. Military exigency requires, and it therefore results, that the dimensions of the canal and its appurtenances must be adequate for the largest vessels upon the oceans.

Between 1867 and 1906 the Cunard Steamship Company constructed 16 large ships. It is interesting and instructive to note the increasing measurements of this fleet. The ships placed in service between the years 1862 and 1874 showed 29 per cent increase in length over those in use before, and $4\frac{1}{6}$ per cent increase in beam. In the next decade the new ships were 12 per cent longer and 30 per cent broader than in 1874. The increases in the third decade were 20 and 14 per cent. The new ships launched up to 1905 were 8 per cent longer and nearly 11 per cent broader than the largest of 1893, while those laid down in 1905 were 23 per cent longer and of $21\frac{1}{2}$ per cent more beam than those in use the year before. There seems to be no recognizable tendency to discontinue this expansion of dimensions of deep-sea vessels.

The voyages from the North Atlantic ports to those of Australasia and the Orient will be the longest existing between great terminal ports and commercial marts, and if larger vessels are generally more profitable than small ones, or if very large freight and passenger vessels are used anywhere, it would seem to be certain that they will ultimately, and probably as soon as the canal is available, seek the interoceanic transit at Panama. That the convenient passage there will, within a quarter of a century, be used by ships 900 feet long and 90 feet beam seems not at all improbable.

The modern lock for ocean-going vessels is a work which an enemy, through stratagem, could with no great difficulty put out of use in an hour or in even a few minutes. If a small detachment from the enemy's fleet, armed with high explosives, landing secretly by night at some nearby shore or inlet, hiding in the neighboring jungle, should surprise the canal guards, or if a few malicious individuals in disguise should succeed in exploding against a lock gate under high water pressure as much explosive as they could carry, they could disable the lock, and could probably cause damage of such colossal magnitude as would put the canal out of use for months. This danger is one that very strict watch and guard might prevent in great measure, but it is well-nigh impossible to provide effectually and always against such peril. Sovereign rulers, bridges, railway trains, buildings, and ships, all under very strict watch, have been destroyed by lawless individuals. Guards would, of course, be always on duty at the danger points and every protective measure possible would be adopted, but if a few desperate characters should set out to disable the canal, and persist in the attempt, regardless of consequences to themselves, the peril would be very great.

As respects vulnerability of the canal or its works to injury and interruption of traffic by a few lawless individuals, the means and results are not difficult to foresee and estimate.

(*a*) The wrecking by explosives of the lock gates while under unequal water pressure, or of the valve chambers where the lock filling and emptying mechanism is situated: The remedy in the one case would consist in the removal of the wreckage and the replacement of the gates; in the other, in possibly very extensive repairs requiring much time. If the controlling gates of an upper lock should be destroyed the summit level would be drained, and if the gates were wrecked so as to afford a free outlet to the water the locks below and the canal itself would be ruined or at the least greatly damaged. In case the gates or controlling mechanism of a lock

were ruined, and free exit for the upper waters was permitted through the chamber, the lock alongside would also be emptied and put out of commission until its neighbor was repaired.

(*b*) The blowing up in a lock of a vessel offered for transit, but designedly laden with high explosives for ignition at the proper moment: In that event the lock would be destroyed, and if it was a lift lock a year or more would be required for repairs.

(*c*) The detonation of some high explosive against or under some portion of a dam built to maintain a summit level: This would be a much more difficult undertaking and one less likely to be attempted. The wrecking by explosives of the controlling and discharging sluices in dams would be easier, but a good many men and considerable time for a successful operation would be necessary. This might be a serious jeopardy at one point for a sea-level canal, but provisional repairs with timber could always be quickly effected.

(*d*) The sinking of a large vessel in the canal prism by any means: Recently the steamship *Chatham*, of 2,500 tons displacement, laden in part with blasting gelatin, met with an accident in the Suez Canal and later was sunk. It had to be blown up and removed before transit could be resumed. The time during which the canal was closed to vessels was ten days. In case of a similar incident at Panama, whether resulting from an accident as at Suez or from design, the consequences, so far as interruption of transit is concerned, might be expected to have a similar result.

The plan proposed by the Board for the isthmian transit will have twin tidal locks near the Pacific terminus which, if disabled, one or both, as under (*a*), would still be usable (after removal of wreckage) for a part of each day (the period of spring tides) in each lunar month, and probably throughout the whole twenty-four hours during the remainder of the lunar month (neap tides).

The plan also contemplates a dam at Gamboa for Chagres control, provided with regulating sluices. There are to be three small dams for the control of minor streams, but there are to be no lift locks, for these, it is claimed, both single and especially in flight, are much more vulnerable than any other essential accessory that has been proposed to be used in any type of canal that has been considered by the Board, and this jeopardy is considered to be a very grave one.

Respecting the liability of the canal to injury and the importance of its defense, the Isthmian Canal Commission in its report dated November 16, 1901, said:

> It is always to be borne in mind that during the excitement of war the canal will not be a safe place for the man-of-war of any nation, no matter who is nominally in control. A small party of resolute men, armed with a few sticks of dynamite, could temporarily disable it without very great difficulty.

The Board believes that this jeopardy will exist at all times during the stress of war.

If an interruption to traffic from any cause should occur while military and naval operations by the United States were in progress, calamitous results would inevitably ensue. If the two belligerents did not include the United States—the custodian of the canal—the closing of the passage might be attempted by one or both the contending powers, and while it would not be done openly, their secret agents would probably conspire to its accomplishment. Such an attempt was feared at Suez while the Russian fleet was passing through that canal en route to the East, and special precautions to guard against the danger were taken by the canal officials and the Egyptian Government. That the risks would be very much greater for a canal in which lift locks are an essential feature is self-evident, and in the opinion of the Board such devices should be rigorously excluded from the design of the canal.

TRANSFORMATION OF A LOCK CANAL INTO A SEA-LEVEL CANAL.

The instructions of the President to the Consulting Board under date of September 11, 1905, contain the following inquiry:

> I desire also to know whether, if you recommend a high-level multilock canal, it will be possible after it is completed to turn it into, or to substitute for it, in time, a sea-level canal without interrupting the traffic upon it.

The Board is of opinion that is is possible to transform a lock canal into a sea-level canal without material interruption of traffic and without serious delays to navigation, although the

operation would not be an easy one, nor can a trustworthy estimate of its cost be made at the present time. The work evidently involves the excavation of immense quantities of rock and earth, much of it at depths considerably exceeding 40 feet below the surface of the water. The Board, having in view the removal of rock at depths less than 40 feet, has adopted as the price for excavating rock under water $2.50 per cubic yard, while for rock excavated "in the dry" it has adopted $1 and $1.15 per cubic yard, except in the Culebra divide cut, where for all classes of materials above elevation 10 a price of 80 cents per cubic yard has been adopted, and for all classes of materials below elevation 10 a price of $1.25 per cubic yard. For the dredging of earth from the canal a price of 25 cents per cubic yard was adopted as against 40 cents per cubic yard for earth in the dry.

As rock is the predominating material to be excavated in depressing the canal from a lock level, it is obvious from the unit prices adopted that a sea-level canal obtained by first building a lock canal would cost very much more than a sea-level canal constructed by a direct process.

An approximate estimate of cost of reducing a lock canal with a terminal lake on the Atlantic side formed by a dam at Gatun, with three locks on the Atlantic side and three on the Pacific, and with a summit level 85 feet above mean tide, to a sea-level canal with the dimensions of prism adopted for the sea-level plan, may be made as follows:

64,500,000 cubic yards earth, kilometer 8 to kilometer 46, at $0.25	$16,125,000
13,400,000 cubic yards rock under water, kilometer 8 to kilometer 46, at $2.50	33,500,000
14,200,000 cubic yards excavation above water in Culebra section, at $0.80	11,360,000
6,500,000 cubic yards rock excavation in Culebra section from surface of water to 25 feet below, at $1.50	9,750,000
35,300,000 cubic yards rock excavation in Culebra section more than 25 feet below water surface, at $2.50	88,250,000
Add for dams and diversion channels and for transforming section of canal between Pedro Miguel and Miraflores, say	25,000,000
Add for removing the locks at Gatun and Pedro Miguel, for modifying the lock at Miraflores, and for removing the regulating works at the Gatun dam and at Miraflores, say	25,000,000
Total cost of transforming lock canal to sea level, on basis of canal sections of Sea-Level Canal Committee, without allowance for contingencies	208,985,000

After a full and careful consideration of all phases of this question the Board has reached the following conclusions:

1. That it is possible to turn any lock canal which it has considered into a sea-level canal without interrupting the traffic upon it.

2. That it is practicable from an engineering standpoint to transform any lock canal which it has considered into a sea-level canal; but that the cost and difficulty of such transformation would be so great as to render such a change impracticable from a financial standpoint until the traffic should have so increased as to tax the capacity of the lock canal, or until other good and sufficient reasons existed for such a change.

3. That if a sea-level canal is to be constructed in the near future it should be built directly without first building a lock canal.

4. That the date for developing a sea-level from an existing lock canal would be so remote, and that there would be so little difference in the time and cost of the transformation for different types of lock canals with a common summit level, that the design of a lock canal should not be controlled by the view that it is subsequently to be so transformed.

5. That the Board is unable to express any definite opinion as to the time required to effect such a transformation into a sea-level canal.

CAPACITY OF CANAL FOR TRAFFIC.

The Board considered that the provisions of the law of Congress by which the construction of an isthmian canal was authorized required that this law should furnish the basis upon which all deliberations should proceed and upon which every conclusion should be established.

The terms of the particular portion of the law which affected the conclusions arrived at by the Board in respect to the dimensions which should be given to the canal locks and prism were conveyed to the Board in the letter signed by Mr. Shonts and printed on pages 10 and 11

of this report, in which the Isthmian Canal Commission laid before the members certain projects for the construction of the canal which had already been submitted to the Commission. The terms relate to the excavation, construction, and completion of a "ship canal from the Caribbean Sea to the Pacific Ocean," and proceed "such canal shall be of sufficient capacity and depth as shall afford convenient passage for vessels of the largest tonnage and greatest draft now in use, and such as may be reasonably anticipated, and shall be supplied with all necessary locks and other appliances to meet the necessities of vessels passing through the same from ocean to ocean."

Having these terms as well as "the rapid developments of naval architecture" referred to by the Commission in the letter of its Chairman in view; having noted that steamers of a length of 740 feet over all and a breadth of 75 feet are at present engaged in ocean navigation, while vessels of a length of 800 feet by 88 feet in breadth are now actually being built, and having the assured opinion that naval development has by no means come to an end, the Board arrived at the following conclusions:

1. That the locks on a canal of any type should be of such usable dimensions as will afford a length of 1,000 feet, a breadth of 100 feet, and a depth of 40 feet.

2. That the prism of the canal for the length to be excavated through the divide (i. e., the length usually known as Culebra cut) should have a depth of 40 feet, a bottom width of 200 feet, and sides with slopes of about ten vertical to one horizontal.

It is considered that with such dimensions the Panama Canal will meet the necessities of the traffic which will use it and the requirements of the law which authorized its construction. It is further considered that if the canal were formed with smaller dimensions than these, experience would prove it to be regrettably deficient in capacity.

The following particulars of existing maritime canals may be useful for the purpose of comparison when regard is had to the fact that not one of these canals is capable of accommodating steamers of the largest draft now employed in the world's trade:

Suez Canal, Egypt.—The Suez Canal presents the nearest analogy to the case of the Panama Canal. It is a sea-level canal without locks, and has a depth of 31 feet 2 inches, which is now being increased to 34 feet 5 inches. The bottom width in the canal proper varies from 108 feet, where the side slopes are very flat, to 118 feet, where the side slopes are steeper, with garages or passing places at intervals for vessels of very large size, as vessels are not allowed to pass each other while both are in motion. In order to avoid this difficulty widening operations are in progress, by which the passing places will be united and the bottom width of the canal increased to a minimum of 147 feet 6 inches.

The largest commercial vessels which navigate the Suez Canal are about 600 feet in length over all by 67 feet 3 inches in beam, with a draft of 27 feet. War vessels of 76 feet beam have passed.

Amsterdam Canal, Holland.—The Amsterdam Canal has only one pair of locks, at Ymuiden, which form the entrance to the canal from the North Sea. The dimensions of the largest lock are 738 feet by 82 feet by 31 feet 2 inches.

The bottom width of the canal is at present 115 feet, which is being increased to 164 feet, and the depth is 27.9 feet, which is being increased to 32 feet 2 inches. The total length of the canal is 15.4 miles.

Manchester Ship Canal, England.—The entrance to the Manchester Ship Canal is controlled by tidal locks, of which the largest is 600 feet long by 80 feet wide. The locks in the length of the canal beyond the influence of the tide are 600 feet in length and 65 feet wide. The falls at the locks (i. e., the differences between the respective high and low levels) vary from 15 feet to 13 feet.

The ruling width of the bottom of the canal is 120 feet, which is gradually being increased to 180 feet, and the depth at low water is 26 feet, which is now being increased to 28 feet.

The length of the tidal portion of the canal is 21 miles and of the portion beyond the influence of the tide, 14 miles, making a total length of 35 miles.

The largest vessels which now navigate the Manchester Ship Canal are 490 feet in length over all by 58 feet 2 inches beam.

Kaiser Wilhelm Canal, Germany.—The Kaiser Wilhelm Canal is furnished with tidal locks at each terminus. The dimensions of the locks are 492 feet by 82 feet by 32 feet.

The bottom width of the canal is 72 feet, with frequent passing places, and the depth is 29 feet 6 inches at mean water level.

The length of the canal, which, as will be seen, affords a single-way navigation, is about 60 miles.

St. Marys Falls Canal, United States.—The St. Marys Falls Canal is not a maritime highway. It connects Lake Superior with Lake Huron and thus forms a link in the great lake navigation system of North America.

It was opened to navigation for vessels of 12 feet draft in 1855. There were then two locks in flight, each 350 feet long and 70 feet wide. Enlargements to meet the growing needs were begun in 1870, and in 1881 the canal was completed, so enlarged in dimensions as to pass vessels of 16 feet draft, and a lock was constructed 515 feet long and 80 feet wide. The capacity of the new waterway was soon seen to be insufficient, and in 1887 the first locks were removed and in 1896 a new one was put into commission 800 feet long, 80 feet wide, and 22 feet over the miter sill, the canal approaches being deepened to 25 feet.

In 1895 a canal on the Canadian side of the boundary was opened with a lock 900 feet long, 60 feet wide, and 22 feet over the miter sill. But the passage has again become inadequate, and a lock with a length of 1,400 feet, a width of 80 feet, and a depth of 25 feet is about to be constructed on the American side, for which purpose the 515-foot lock is to be removed, the new one to occupy its site.

The canal proper is only one and three-fifths miles in length, but the improvement in the lake channels extends over a length of 34 miles. The width of the canal varies from 108 feet at the narrowest place to 1,000 feet at the lower entrance. The widths of the river channels vary from 300 to 600 and 1,500 feet. The depth of the canal is 25 feet and that in the channels is 21 feet. The largest vessels which now use the St. Marys Falls Canal are 569 by 56 feet, with a draft of 20 feet.

It will be observed that in the case of each of the foregoing canals (except the Kaiser Wilhelm Canal) operations are in progress for the widening and deepening of the waterways, experience having shown that growth in the dimensions of ships has advanced far more rapidly than was conceived to be possible when the canals were projected, and therefore that their original dimensions were insufficient for the exigencies of modern traffic. There is, so far as the Board is aware, no example on record of the promoters and designers of a maritime highway having had occasion to regret that they had given too great dimensions to the highway, but there are many cases in which they have found that dimensions originally regarded as ample have been proved to be far too meager.

As this report is being written the public press announces that orders have been given by the Imperial Government of Germany for the preparation of plans for the enlargement of the Kaiser Wilhelm Canal.

A just estimate of the growth of traffic on the Panama Canal can not be formed from the statistics of the growth of trade on any existing waterway. The unprecedented increase in the population of the world which has taken place as civilization has advanced—it is generally agreed that the civilized population of the world was doubled in the course of the nineteenth century—and the movement of the surplus population westward, i. e., from Europe to North and South America, must of necessity not only proceed but proceed at an accelerated rate, so that the growth of trade on the interoceanic highway will not be, as in the case of the Suez Canal, merely due to the expansion of the volume of commerce which takes place year by year as facilities are presented for the movement of commodities, but to that expansion multiplied by the increasing requirements of a constantly expanding industrial population.

It is therefore essential that the Panama Canal should furnish a double road for traffic throughout, and we consider that the locks should be built in pairs; that twin locks should lie side

by side, and that the different lengths of the canal should be of such dimensions as to permit two of the ordinarily large-sized commercial steamers to pass each other at any part of the journey.

When the canal is used for the transit of large line-of-battle ships or commercial vessels of largest size, all other vessels should be moored to one side so as to leave those great vessels as clear a course as practicable.

THE CONTROL OF THE CHAGRES AND OTHER STREAMS.

The Chagres has been considered to be an element of great difficulty in the construction of the Panama Canal from the earliest stages of discussion of the project. Its general character above Bohio is that of a clear mountain stream, although that observation is more applicable above Gamboa than below that point, its watershed being much more mountainous in its upper portions than between Gamboa and Bohio. The entire area drained by this stream has never been determined, even with approximate accuracy, but it has been considered under various estimates to range from 700 to 875 square miles above Bohio, or from 450 to 625 square miles above Gamboa. The adoption of the latter as the site for the dam of the great controlling reservoir makes it necessary to consider, in connection with the problem of control of the Chagres, only the watershed above the dam, but provision has been made for the control or diversion of all the streams contributary to the Chagres from Gamboa to the Colon terminus.

The entire watershed of the river above Gamboa is bold and quick, so that a heavy downfall of rain within its limits results in a rapid rise of the river. Inasmuch as the total annual precipitation in the Chagres watershed may reach from 100 to 125 inches, it is obvious that under existing conditions of run-off severe floods may be expected, although the river is not a large one. Nearly the entire watershed under consideration is heavily wooded, with a density of vegetation characteristic of a tropical country, and the steep clayey and rocky slopes afford all the conditions required for a rapidly varying stage of river in the rainy season.

At the site of the Gamboa dam, 30 miles from Colon, the river bed has an elevation of about 50 feet above mean sea level, but the deepest rock is at practically sea level, making it necessary to sink the foundations of a dam to a maximum depth of only 53 or 54 feet below water at the low stages of the river before finding material on which to form a suitable foundation bed. At the proposed site of the dam the high hills approach each other within 2,020 feet at an elevation of 180 feet and within 1,170 feet at the bottom of the valley. The earth overlying the rock is of moderate depth, so that the conditions are favorable for the construction of any type of dam which may be adopted.

Fortunately for the solution of the problem of control of the river, more data regarding rainfall and river flow have been collected by observations at Gamboa than at any other point in the river's course. The location is also well adapted for the construction of a dam to serve the purposes of controlling floods or feeding the canal, and for the development of a power plant to drive electrical machinery for lighting, operating the Panama Railroad, and for other purposes, as it is the point at which the river in its flow toward the sea first cuts the line of the canal. If, therefore, the control of floods is satisfactorily accomplished at Gamboa, there remains to be considered only the discharge of contributary streams below that point, which in the aggregate is relatively so small that its control is a matter of little difficulty or expense.

Observations, more or less complete, of the discharge of the Chagres River at Gamboa have been maintained from 1882 to the present time. Its flow in the dry season may fall to less than 300 cubic feet per second, while in the flood of 1879 it is supposed to have risen for a short period to nearly 80,000 cubic feet per second. During the past fifty years there have been six severe floods, all of which have occurred in the months of November or December—that is, toward the end of the rainy season. The following table gives some of the main elements of these various floods as they have occurred at Gamboa:

Date of flood.	Cubic feet per second.		Height above low water at Gamboa.	Period when discharge was above 20,000 cubic feet per second.
	Maximum.	Maximum average in 48 hours.		
November—			*Feet.*	*Hours.*
1879	78,614(?)	65,000(?)	36.65(?)	
1885	64,488	43,404	31.50	46
December—				
1885	44,923	32,421	24.11	43
1888	58,132	48,278	31.37	58
1890	65,371	34,752	31.82	35
1893	43,086	27,971	25.33	32

The data relating to the floods between 1885 and 1893 have been deduced from accurate observations; but such is not the case with that of 1879, the greatest of all. No hydrographic observations along the river were made at that time, but certain high-water marks were approximately determined subsequent to the flood, largely from such information as could be obtained from the memory of ordinary observers. These have been compared with high-water marks of floods since 1879, whence maximum discharges at Bohio have been estimated and corresponding maximum discharges at Gamboa inferred from them. The approximate results given in the above table for the 1879 flood are those which have been found in this manner by the careful work of Gen. Henry L. Abbot, member of the Board.

Certain general results of value in connection with the problem of the Chagres River at Gamboa follow from an inspection of the preceding tabulation. It is seen at once that the maximum discharge of any flood of record during the past fifty years has not exceeded about 65,000 cubic feet per second, but that the approximate maximum discharge of the 1879 flood reached nearly 79,000 cubic feet per second. Inasmuch as there have been but six severe floods in half a century, it is obvious that they are of infrequent occurrence.

The next important conclusion established by this long record is the fact that these floods are of short duration. A discharge in excess of 20,000 cubic feet per second has never been observed to last more than 58 hours, although that limit may have been exceeded in 1879. It is convenient, in view of this fact, to deduce the maximum average discharge for a period of 48 hours in each case, as the resulting aggregate volume will represent what may practically be considered the total flood flow of the river. The third column of the table shows that the maximum average 48-hour discharge in the six severe floods has ranged from about 28,000 cubic feet per second to an estimated maximum average of 65,000 cubic feet per second for the flood of 1879. Finally, the greatest high-water elevation above low water during these floods is seen in the fourth column of the table to vary from about 25 feet to the estimated elevation of 36.65 feet for 1879. The preceding data are sufficient for the determination of complete reservoir control of the Chagres floods by a dam at Gamboa.

A reservoir created by the proposed dam may have two important functions—that of control only, in the case of a sea-level canal, and those of control and water supply in the case of a lock canal. It will be seen that if the reservoir is of sufficient capacity to control satisfactorily the floods of the Chagres, there will be abundant storage capacity for supplying the summit level of any lock plan.

In providing reservoir capacity for the control of the Chagres floods, it is to be borne in mind that two floods may follow each other with only a short intervening period, and that such a succession of floods may be both preceded and followed by comparatively high water in the river, although not sufficiently high to be considered a flood flow. It is obviously impracticable to estimate the severest combined effects of such conditions for the future, but the observed records of flow during the past twenty years are sufficient to make an entirely safe provision for any exigency of combined high water and flood flow, especially in view of the fact that two

severe floods, like either of those of November, 1885 or 1888, in close succession have never been observed in such a connection, not to cite the phenomenal flood of 1879.

If a dam be constructed at Gamboa with an elevation of its top at 180 feet above mean sea level, or 130 feet above the river bed, and if the highest flow line of that reservoir be taken at 170 feet, the area included within that flow line will be 29.47 square miles. With the minimum depth of water of 40 feet provided for the sea-level canal, the minimum wetted cross section would have an area of over 8,000 square feet, so that if 15,000 cubic feet of flood water per second from the Chagres be permitted to enter the canal prism at Gamboa, the resulting current, if the entire quantity admitted flows in one direction, will be but one and one-fourth miles per hour, a negligible quantity so far as its effects upon navigation are concerned: but the plans for a sea-level canal contemplate a provision which would permit the discharge through the canal prism and regulating sluices near the tidal lock on the Pacific side of approximately one-third of this Gamboa discharge, and to that extent, at least, dividing the flow between the two oceans and consequently reducing the current velocity. For the purposes of estimation in connection with this problem of flood control the Board has therefore assumed that the controlling sluices to be provided in the Gamboa dam may admit the flood waters of the Chagres to the canal prism at the uniform maximum rate of 15,000 cubic feet per second.

If a flood should occur with a discharge equal to that estimated for 1879, viz. 65,000 cubic feet per second at Gamboa for a period of forty-eight hours, and if a uniform outflow of 15,000 cubic feet per second be permitted during the same time, there would be accumulated in Gamboa Lake 8,640,000,000 cubic feet of water, which is that portion of the volume of the lake included between water surfaces at elevations of 159 feet and 170 feet above sea level. Furthermore, a uniform outflow from the lake at the rate of 15,000 cubic feet per second would discharge the entire maximum average 48-hour flow of the 1879 flood in 8.7 days. It is seen, therefore, that there would be no practical difficulty in depressing the surface of the water in Gamboa Lake between two severe floods sufficiently to receive the entire maximum average 48-hour flow of such a phenomenal flood as that of 1879.

The capacity of flood control provided in such a lake as that under consideration is further illustrated by the fact that its volume between water surfaces at 108 and 170 feet above mean sea level is sufficient to take the aggregate discharge of three times the maximum average 48-hour flow of the 1879 flood without any water escaping through the regulating sluices of the dam; or the volume between elevations 128 feet and 170 feet will hold three times the flow of such a flood if a uniform discharge of 15,000 cubic feet per second be permitted concurrently through the regulating sluices.

These computations demonstrate conclusively that the controlling capacity of the Gamboa Lake as proposed by the Board is ample for all the exigencies of flood flow which can ever occur in the Chagres River without any other regulating or controlling aid, especially when it is observed that the highest mean monthly discharge for the rainy months of any year since 1890 (for 1892) is a little less than 5,300 cubic feet per second. There would only be required a simple grade of supervision, under which the water surface would always be depressed immediately after any flood low enough to receive any subsequent sudden flood flow which might possibly occur. This grade of supervision requires no special estimation or prevision of future events, but is quite within the ordinary administration of this feature of canal maintenance and operation.

The elevation of water surface assumed at 170 feet is sufficient to permit the use of an open channel between the Chagres watershed and the headwaters of the Gatun River for the discharge of surplus flood waters in that direction, should it ever be required. The controlling capacity of the Gamboa Lake, however, is so complete and satisfactory that the Board does not believe that it will ever become desirable to construct this open channel across the divide between the Chagres and Gatun watersheds.

The Gamboa Lake affords complete regulation and control of the Chagres River above Gamboa. It has already been stated that there are small streams now discharging into the Chagres River below Gamboa which must be taken care of during the construction of the canal. Ample provision has been made for the control of these smaller streams, either by utilizing the

diversion channels planned by the old French company and now partially constructed or by constructing dams across their courses high enough to compel them to reverse their flow and discharge through the divides at the heads of their watersheds. Among the latter class are the Caño Quebrado and the Gigantito, the reverse flow of which would be discharged into the headwaters of the Trinidad and the Gigante, whose reverse flow would be turned into the basin of the Peña Blanca marsh and pass on to the sea through the Chagres channel and its existing diversion. The Gatun River (sometimes called the Gatuncillo) would discharge its waters and those of the Mindi through the Gatun diversion, nearly completed by the old company, into that part of Manzanillo Bay known as Puerto Escondido. After the completion of the canal the aggregate observed flood discharge of all the streams entering it below Gamboa—the Caño Quebrado, Gigante, and Gigantito being diverted as hitherto observed—would amount to less than 4,000 cubic feet per second (see p. 240, Report of the Isthmian Canal Commission, 1901), a quantity that would exercise no material influence upon currents in the canal channel.

A similar observation will apply to the aggregate flood flow of the small streams between the Culebra cut and the Panama terminus, which may be taken into the canal prism at the completion of the work, but which would be controlled by diversion channels now largely excavated and by other temporary works of a simple and inexpensive character during construction.

The difference between the flood discharge of the Chagres at Bohio and at Gamboa, which discharge is partly observed and partly estimated, is stated by General Abbot to be 34,000 cubic feet per second, while the gauged flow of the contributing streams between Gamboa and Bohio is given by him as 26,335 second-feet.

Taking the flood flow of these streams at 32,000 second-feet, it is found that the maximum current velocity in the canal—which would be at Bohio due to the flow of said streams which are not diverted, together with 15,000 second-feet coming from the upper Chagres through the sluices contemplated—will be but 2.64 miles per hour, a velocity which will not interrupt navigation. As a part of the upper Chagres discharge will flow to the Pacific, and as the highest mean monthly discharge of this river in the rainy season at Gamboa is but 5,300 second-feet, as General Abbot points out, the currents in the canal will usually not exceed one mile per hour, and at extreme low water in the river there will scarcely be a perceptible current. At such times the water in the canal prism will be brackish, without currents save as influenced by the insignificant Caribbean tide.

The tributary streams, whose beds at point of junction with the canal are considerably above the prism of the latter, will be discharged over masonry-stepped aprons or through metallic discharge pipes, or these beds will be sloped and lowered so as to prevent objectionable currents at junction points. The means for the accomplishment of these results are such as are in common use on nearly all important canals.

During three-fourths of the time these streams discharge an insignificant amount of clear water. When they are in flood they will bring down some silt, and it is recognized that the maintenance of the navigable canal channel will require a small amount of dredging.

DAMS.

The consideration of the projects presented by Mr. Bates, Major Gillette, and others has raised certain questions regarding the types of dams, which the Board believes can better be treated as an independent subject than in connection with the plans presented by Mr. Bates or others, especially as some of these considerations bear also upon the design of the dam at Gamboa recommended for construction in the sea-level plan.

In these projects or plans it has been proposed to retain terminal or other lakes by earth dams resting upon the natural soil, consisting of sand, gravel, or sandy clay; or, as at La Boca, at the Panama end of the canal, upon mud and silt between San Juan Point and the easterly shore of the Rio Grande estuary near Sosa Hill, also between Sosa and Ancon hills. Under some of these dams or dikes the plans or proposals indicate that shallow sheet piling might be used in some cases, and in other cases that feature is absent. There are grave reasons for

doubting the stability of these types of structures under such circumstances. The earth dams which have already been built for the retention of large bodies of water, some of them exceeding 100 feet in height, show that this type of structure may give satisfactory results when properly designed and constructed, but the character of the foundation material on which such dams are built and the means for preventing dangerous seepage underneath or through such foundations must always be carefully considered. The earth dams which have been proposed for terminal lakes at the Caribbean and Panama ends of the canal are proposed to be placed directly upon the natural soil at Mindi or Gatun, near Colon, or on the silt, mud, and clayey material at La Boca, near Panama. It has not been proposed to dredge out the soft and yielding material at either place other than possibly a shallow strip of the natural surface, nor has it been proposed to sink a curtain either of masonry or of timber, such as deep sheet piling or of any other material, to cut off percolation or seepage underneath the structure.

These are disquieting considerations in the design of dams to retain water of depths varying from 30 to possibly 85 feet or more. The subsurface material at Mindi and at Gatun, extending down to the hard indurated sandy clay or soft rock, attaining a maximum depth of 258 feet, is in large part of a comparatively fine character, consisting of sand and clay in varying portions and in various degrees of admixture, but the borings have also shown coarse sand and gravel with water flowing through it and out of some of the pipes used in making the examinations. As a presumption or speculation it may be stated as probable that most of this material under the weight of an earth dam would be so nearly impervious that only a small or negligible quantity of water would find its way through, even with the increased head of the reservoir; but that is simply conjecture.

It is more than possible, it is highly probable if not certain, that at various points the material is sufficiently loose in texture to permit seepage or percolation in dangerous quantities. Nothing is more common in the sandy deposits of river valleys and in all sandy material than small passages or channels through which water moves, varying in size from thread-like openings to those sufficient to yield flowing wells of large discharge. Extended experience in dealing with the underground flow of subsurface waters in many places in the United States, and wherever investigations in that field of hydraulics have been made, shows this to be the case.

Vast volumes of water are daily taken from subsurface sands, and have been for years, for the public water supply of many cities in the United States, prominent among which is the borough of Brooklyn of the city of New York. All such experience indicates conclusively the danger of depending upon stopping, or even materially diminishing, such a flow by the weight alone of any superincumbent mass of earth.

The assumption of negligible seepage or percolation below these earth dams must necessarily be based upon the practically uniform quality or distribution of the material claimed to be essentially impervious. It is safe to state that this is never the natural condition over any considerable portion of a profile at the site of a great dam. The fine or coarse sandy or even gravelly material found in such locations has been deposited under radically varying conditions of floods and resulting currents separated by low-water intervals, so that it is physically impossible that even practical uniformity either as to kind of material or rate of deposition should result. The inevitable consequence is the great variation in strata, more widely different at some locations than others, but in all cases there is a wide departure from uniformity. It is one of the early and marked experiences in the construction of filter beds that the most scrupulous care must be taken in placing the sand or other filtering material so as to avoid variation in its character or its density of texture. If there is a lack of uniformity or a place at which a surface of separation between two portions of material of different character or variation in compactness exists, the water invariably finds such passages of decreased resistance to flow, and forms for itself small channels through which it escapes with readiness without being filtered. Indeed, the degree of care which is required to accomplish the uniformity of texture or compactness necessary for a proper flow without these small channels is shown by the fact that men are frequently forbidden to walk over the surface of a new sand filter, so as to avoid the

separating surfaces between the increased compactness under the foot and the looser material surrounding the footprint.

A careful consideration of these conditions of actual experience will show that any computations apparently indicating that the seepage or percolation taking place through a great geological profile like that at the sites of the proposed dams at Mindi, Gatun, Bohio, Gamboa, or at any similar location, are based upon assumptions without any warrant in engineering experience and involving the grave danger of excessive percolation under an earth dam.

The dam at La Boca between San Juan Point and Sosa Hill, unless carried down to bed rock at that location, would be placed upon a far worse foundation even than that proposed at Gatun or Mindi. The La Boca site is one covered by an ooze of mud and silt, with some sandy material overlying the rock. It is practicable to construct here an earth dam, with a heavy masonry core running down to bed rock, whose stability would be beyond question. Such a structure would be far more costly than a great mound of earth placed upon the mud and silt forming the natural bottom of the Rio Grande estuary. Unless some feature equivalent to that of a heavy masonry core characterizes the design of the dam at this point, or unless resort be made to dredging down to bed rock or near to it and refilling with suitable material, or an earth dam at this location be made very massive, it would be in grave danger of being pushed bodily out of place by the pressure due to the head of water in the reservoir.

The nearest approach to the earth dams which have been advocated in these localities is the great north dike or embankment of the Wachusett reservoir, a part of the new Boston water-supply system very recently constructed by Mr. F. P. Stearns, a member of the Board. In that case, deep and heavy sheet piling or deep excavation of the natural soil with refilling of suitable material was employed to prevent seepage or percolation wherever it was apprehended that the nature of the substrata was such as to permit it. It is the judgment of the Board that such safeguarding features as core walls, sheet piling, or the removal of unsuitable material should not be omitted in similar structures on this work of extraordinary magnitude and supreme importance.

The United States Government is proposing to expend many millions of dollars for the construction of this great waterway, which is to serve the commerce of the world for all time and the very existence of which would depend upon the permanent stability and unquestioned safety of its dams. The Board is therefore of opinion that the existence of such costly facilities for the world's commerce should not depend upon great reservoirs held by earth embankments resting literally upon mud foundations or those of even sand and gravel. The Board is unqualifiedly of opinion that no such vast and doubtful experiment should be indulged in, but on the contrary that every work of whatever nature should be so designed and built as to include only those features which experience has demonstrated to be positively safe and efficient.

The considerations of these and other reasons have prompted the Board to recommend at Gamboa either an earth dam with a heavy masonry core carried down to bed rock, or an all-masonry structure founded at the same depth and upon the same material.

THE SEA-LEVEL PLAN RECOMMENDED BY THE BOARD.

(A) ALIGNMENT AND DESCRIPTION.

The width of the Isthmus at Panama is less than at any other point where it is feasible to construct a canal open throughout between the oceans. The width, less than 36 miles in a straight line, is only five miles greater than at the narrowest place, San Blas, but an open cut is impracticable there. The summit on the Panama route, which was 333 feet above the sea originally, is lower than at any other known point between the Arctic Ocean and the Straits of Magellan, Nicaragua only excepted, while at the latter place, by reason of the greater distance between the oceans, the volume of material to be removed to form a lock canal is much greater than at Panama, and a sea-level canal is obviously impossible. At Panama alone is a sea-level canal in open cutting feasible, and the Board has no doubt of the practicability of such a canal.

The general direction of the Isthmus in this vicinity is nearly northeast and southwest and the general route for the canal nearly northwest and southeast. The summit at Culebra lies about nine miles from Panama Bay, and the distance between the point on the northern approach to this summit where the present elevation on the proposed canal axis is 100 feet above sea level to the point on the southern approach to Culebra at the same height is nearly nine miles. Within this distance will be found nearly one-half the total excavation required to make an open channel at the sea level adequate in dimensions and capacity to pass not only the largest existing commercial and naval vessels, but the largest which may be expected to require transfer between the Atlantic and Pacific oceans.

The line adopted by the Board for the sea-level canal which it recommends for construction is in general that which was adopted by both the old and the new Panama Canal companies for their projects. While the Board approves this alignment for the purposes of ultimate construction, it believes that further examination should be made for the reduction of curvature and for other improvements of the line in detail, particularly at the deepest portion of the Culebra cut. It is believed that a judicious relocation between Emperador and Cucaracha will reduce the excavation considerably with only a comparatively small change of alignment. In this manner, at this particular portion of the line, excessive excavation on the easterly side of the deep part of the Culebra cut may be avoided, at the same time utilizing the entire volume of existing excavation between Emperador and Cucaracha.

At the Colon and La Boca terminals, however, it is the judgment of the Board that material changes should be made both in the plans of these terminals and in the alignment to eliminate considerable curvature. The terminal plans recommended by the Board are described under the section of "Harbors."

The initial point of the axis of the canal is located in Limon Bay, about one mile northwest of Manzanillo light, at the beginning of the dredged entrance channel, where the depth of water is at least 40 feet at low tide. From that point the axis of the dredged approach channel runs straight to near the southern limit of Limon Bay, where, near Mindi, a curve unites it with the center line of the canal, as partially completed by the old company. From Mindi the proposed line follows the partially excavated canal through the low marshy ground nearly to Bohio, a distance of 12 miles. The canal line first cuts the course of the Chagres River at Gatun, seven miles from Colon, and then repeatedly cuts it from that point to Bohio. The excavation throughout this entire distance from the sea channel to Bohio can be made by the simple operation of dredging, but there is some hard clay to be removed.

After passing Bohio the ground rises gradually toward Panama and radically changes in character. A considerable quantity of rock must be removed at Bohio, and the same material is found in considerable quantities throughout almost the entire remaining distance to the shore of Panama Bay. The canal line from Bohio follows practically the general line of the Chagres River, cutting or coinciding with the bed of the river at many points, to Obispo, 14 miles from Bohio. The bed of the river at Bohio is practically at sea level, and about 50 feet above sea level at Gamboa near Obispo. While the surface of the ground is varied and broken, the ascent is gradual and nearly uniform to Obispo. The material to be excavated is clayey and sandy in large part, although rock in substantial quantities is found projecting above sea level at some points, mostly in the lower part of the proposed excavation. The excavations made by the old company along this portion of the route were generally shallow, although deeper at some points where hills exist, but constituting a nearly continuous surface cutting. That company excavated very little rock in this vicinity.

The general course of the canal from Colon to Obispo is southeast, and in part due south. Although there are several curves they are all of large radii, the shortest are being one and four-tenths miles in length.

The vicinity of Obispo, about three-fourths of a mile only from Gamboa on the Chagres River, is a marked one in the alignment of the canal. At this point the valley of the Chagres, passing upstream, trends sharply to the northeast nearly at right angles to its course below

Gamboa, but the canal line continues toward the southeast, i. e., toward Panama. The great reservoir for controlling the floods of the Chagres, to be created by a dam at Gamboa, is described in another section of this report. The waters escaping from that reservoir through regulating sluices will enter the canal prism about three-fourths of a mile north of, or below, Obispo.

Continuing toward Panama the ground rises at a more rapid rate. At Obispo the great summit cut may be said to begin, as there is at that point a more abrupt rise in the surface of the ground and a correspondingly rapid increase in the depth of excavation. There is much rock to be removed from the canal prism at Obispo, and that material continues to form by far the greater part of the excavation through the divide to a point beyond Pedro Miguel, on the Pacific slope of the Cordillera. The deepest part of the summit cut at Culebra is about five and one-half miles from Obispo. The maximum depth of excavation required for a sea-level canal will be about 373 feet below the original surface where the axis cuts the saddle. The deepest part of the present cut, however, is about 160 feet below the original surface, or about 213 feet above the bottom of the excavated channel required by the sea-level plan. The length of the main part of the great summit cut is about nine miles, from Obispo to Pedro Miguel. The material to be removed is partly of indurated clay so hard as to be classed as soft rock, and partly of hard rock with a surface covering of clay.

The heaviest work of excavation done by the old and the new French companies is shown by this cut between Emperador and the southerly slope of Culebra Hill, where the canal line intersects the course of the Rio Grande River.

As has already been indicated in this report, it is believed that a slight relocation can be advantageously made along this portion of the line between Emperador and the little village of Cucaracha, on the Pacific slope of the divide. A careful study should be made to ascertain whether it may not be feasible to throw the center line of the canal a little to the westward of its present position in the deepest part of the Culebra excavation, so as to avoid further cutting of the high portion of the hill on the easterly side of the line. This would enable the further cutting to be made in the lower hill on the westerly side. It is possible also that improvement in the alignment at Emperador may be made, although at the expense of cutting more deeply into the hill at that point.

The canal line reaches low marshy ground nearly at sea level at a point about two miles below Pedro Miguel. From that point to deep water in Panama Bay the Board has adopted a different alignment from that of the French companies. The latter followed as closely as possible the course of the Rio Grande to its mouth at La Boca in order to avoid rock excavation, but that alignment included two curves which are avoided in the new location. The location recommended by the Board is practically a straight line from a point a short distance from Miraflores through the Rio Grande swamp; but opposite Corozal a low ridge or spur from the eastern highland is crossed, in which ridge the borings show rock. Advantage is to be taken of this conformation to locate on the rock foundation a wide spillway with regulating sluices primarily for discharging into the Rio Grande and so into the Pacific a part of the Chagres flow at Gamboa coming through the Culebra, but the sluices may also be used to regulate and reduce the currents in the canal while the tidal lock is open.

The canal continues in a straight line through the swamp to and through the saddle between Ancon and Sosa hills, where the tidal lock is to be placed, and thence to deep water off Isle Flamenco. From Miraflores to the lock the canal will be leveed, so as to prevent the tidal flow from entering it.

The French plan required a tidal lock at Miraflores some five miles from the bay shore, whereas in the new location it will be in the low Ancon-Sosa saddle, thus bringing it almost to the margin of the shore and avoiding the long approach channel wherein tidal currents would be generated if the locks for their control were at Miraflores, far inland.

Experience in the navigation of maritime canals shows that the area of the wet section of the prism must be at least four times that of the immersed section of the ship passing through it at a speed of six miles per hour. The smallest area of cross section of the canal prism, in rock

excavation, exceeds 8,000 square feet. The dimensions adopted by the Board, therefore, will permit a speed of six miles per hour for the largest existing vessels using it, and of not less than eight miles per hour for the average ship. For a ship of 90 feet beam and 38 feet draft a speed of four or five miles per hour might be considered sufficient.

These speeds will enable ships of the largest size to pass through the canal in seven hours if the gates of the tidal lock at Panama are open, as they will be for more than half the time, or in eight hours during high spring tides, when the tidal locks will be in use. The time of passage of the average ship will probably be between five and six hours with the gates of the tidal lock open, or one hour longer when the tidal lock is in use. For a ship of the exceptional size given the time of transit might reach ten hours.

After the completion of the canal the tracks of the Panama Railroad can judiciously be placed on one of the berms of the canal, at least between Bohio and Miraflores, as the railroad will then lose its present character and serve local and passenger traffic only, besides being a tender to the canal for its maintenance and for other similar purposes. Power for operating it would be developed at the Gamboa dam.

Some dredging will be required in the harbor channels as well as in the canal proper, but this will be nearly the same for either type of canal.

The entire length of the line between shore lines is a little over 40 miles, while the total distance including harbor channels is 49.35 miles.

The total length of curves is 19.17 miles, leaving 30.18 miles of tangents or straight portions.

Summarized, the sea-level canal as recommended by this Board is a channel commencing at the 41-foot contour in Limon Bay, about 5,000 feet northerly of a line between Toro and Manzanillo lights, protected by two diverging jetties with a width of opening of 1,000 feet; thence with a straight channel 500 feet in width at the bottom and a depth of 40 feet, protected by a parallel jetty on the west and by Manzanillo Island on the east, to Mindi, whence the land canal begins.

This canal is designed with a depth of 40 feet and a bottom width of 150 feet in earth, with side slopes adjusted to the nature of the ground so as to give a surface width of from 302 feet to 437 feet. In rock the section is to be altered so as to have a bottom width of 200 feet and a surface width of 208 feet. At the Pacific end the canal is to be protected by a tidal lock located between Ancon and Sosa hills. Beyond this tidal lock there is to be a straight channel projected into Panama Bay, with a bottom width of 300 feet and extending for a distance of three and three-fourths miles to the 45-foot contour.[a]

The width adopted for the canal will be sufficient to permit steamers to maintain a speed of six to eight knots per hour, and to allow two ordinary merchant steamers to pass each other on the line of the canal without stopping.

At Gamboa there is to be located a dam, either of masonry or of earth and masonry combined, for the control of the Chagres, and at Corozal, sluices by which, during half the tide period when the level in the Pacific is lower than that in the Atlantic, water can be discharged from the canal into Panama Bay.

The following tabulation gives the total excavation as very carefully computed from the data supplied by the Isthmian Canal Commission, supplemented by data collected at the instance of the Board:

Estimate of excavation of a sea-level canal 40 feet deep.

[December 22, 1905.]

Stations.	Classification.	Cubic yards.		Unit price.	Amount.	
41-foot contour to shore line of Limon Bay, 0 to mile 3.92.	Earth	2,781,668		$0.15	$417,250.00	
	Indurated clay	5,566		.70	3,896.20	
	Coral	135,500		1.50	203,250.00	
			2,922,734			$624,396.20
Shore line to Mindi, mile 3.92 to mile 5.49	Earth	7,695,885		.25	1,923,971.25	
	Indurated clay	2,351,588		.70	1,646,111.60	
			10,047,473			3,570,082.85

[a] Contours refer to mean sea level.

Estimate of excavation of a sea-level canal 40 feet deep—Continued.

Stations.	Classification.	Cubic yards.		Unit price.	Amount.	
Mindi to Bohio, mile 5.49 to mile 17.22	Earth	21,730,653		$0.25	$5,432,663.25	
	Rock above sea level	628,088		1.00	628,088.00	
	Rock below sea level	2,198,643		2.50	5,497,107.50	
			24,557,584			$11,557,858.75
Bohio to Obispo, mile 17.22 to mile 30.96	Earth	48,787,149		.40	19,514,859.60	
	Rock above sea level	4,490,926		1.15	5,164,564.90	
	Rock below sea level	7,396,362		2.50	18,491,905.00	
			60,674,437			43,171,329.50
Obispo to Pedro Miguel, mile 30.96 to mile 39.04	All material above +10	93,697,408		.80	74,957,926.40	
	All material below +10	16,194,302		1.25	20,242,877.50	
			109,891,710			95,200,803.90
Pedro Miguel to Miraflores, mile 39.04 to mile 40.77	Earth above sea level	2,136,125		.40	854,450.00	
	Earth below sea level	300,000		.25	75,000.00	
	Rock above sea level	518,881		1.15	596,713.15	
	Rock below sea level	2,474,138		2.50	6,185,345.00	
			5,429,144			7,711,508.15
Miraflores to south end of Sosa lock, mile 40.77 to mile 45.37	Earth	6,106,828		.40	2,444,731.20	
	Rock nearly all below sea level	5,223,700		2.50	12,659,250.00	
			11,330,528			15,103,981.10
South end Sosa lock to 45-foot contour in Pacific, mile 45.37 to mile 49.35	Earth	3,508,945		.15	536,341.75	
	Rock	2,663,922		2.50	5,659,805.00	
			6,172,867			6,196,146.75
	Total		231,026,477			183,136,107.30

Contours refer to mean sea level.

(B) HARBORS.

The harbor of Colon.—A first-class natural harbor is not found at either terminal of the canal, but good harbor accommodations can be created without unusual difficulty or extraordinary expense.

Limon Bay, on the easterly side of which is the city of Colon, must be the Caribbean terminal of the canal. It is a rectangular indentation of the low-lying coast, with a width of two and three-fourths miles and a length approximately in a north and south direction of a little more than four miles. It is shallow, freely open to the sea from the north, and but little less exposed to the northeast and northwest. The extreme range of tide seldom exceeds two feet six inches except under the influence of high winds. The mean range is about one foot six inches.

The depth of water at the entrance to the bay in its central portion is from 30 to 38 feet opposite the water front of Colon. The southern half of the bay is so shallow as to be of no value for harbor purposes. The depth of water varies from 28 feet opposite Cristobal Point, and gradually shoals to the gently sloping sandy beach at the extreme southerly end.

The currents in the bay have little velocity. One, called the Rio Magdalena current, comes from the east and is at times felt along the eastern and western shores, but chiefly along the latter. The discharge of a large portion of the Chagres River through the partially excavated canal prism between Gatun and Mindi, and through the latter into the head of the bay, produces a gentle outward current which opposes that described above. These currents are neither constant nor strong, and are often influenced by the wind. The tides are so small and the tidal section so large that they have little influence upon the currents.

The greater part of the bottom of Limon Bay is soft. A large number of observations have been made under the direction of the Isthmian Canal Commission by sounding with railroad rails, weighted where necessary by the hammer of a floating pile driver. The silt or other sediment forming the bottom is of such character that these railroad rails used as sounding rods usually sank from 10 or 15 feet to as much as 30 feet by their own weight. This material, therefore, is readily moved when the water is shallow by storm waves or by currents induced by the wind or other agencies.

There is undoubtedly a decided movement of the material of the soft bottom in the easterly portions of the bay south of Cristobal Point by storm waves, although the rarity of the storms prevents the aggregate of movement being very large. Since surveys were made by the old Panama Canal Company there a sensible advance of the shore line at the southeastern limit of the bay has been observed, particularly in the vicinity of the mouth of the Mindi River, where the

sediment carried by such of the flood waters of the Chagres as is here discharged is deposited. That portion of the harbor outside of the five-fathom line has been but little affected by the deposition of sediment, but there has apparently been some slight advance of this contour. With the diversion of the Mindi there should be no further decrease of depths in the bay. These physical characteristics have been carefully considered in the design of a terminal harbor at Colon.

In spite of this soft material and the depth of the bay, the anchorage is good enough for such conditions of weather as ordinarily prevail at Colon. The best anchorage is about one-half mile to a mile off the water front. Ships have no trouble in holding in this location except in the rare instances of very high winds. The swells that roll into the harbor at times from remote storms in the Caribbean do not give any serious trouble to vessels at anchor.

Limon Bay is open to the north, and northers blow directly into it. These northers are severe windstorms, usually accompanied by rain, generally from slightly west of north, but occasionally a little easterly of that point. They occur, on the average, not more than three or four days in the year and during some years not at all. During these storms the wind blows with high velocity, driving storm waves of great magnitude and force directly into the bay. At such times ships can not lie at anchor nor be berthed alongside the piers on the water front without grave danger. Indeed, vessels unable to get away in time to escape such storms have been wrecked on the water front of Colon as well as at other points in the bay. So many ships have lost their ground tackle while at anchor off Manzanillo Island that not infrequently anchors and chains are brought up by ships while raising their own anchors. During the very severe norther of November, 1879, a brig drawing 18 feet at anchor in five fathoms touched bottom in the trough of the sea and lost her sternpost and rudder. When northers begin to blow, all the steam vessels invariably get to sea as soon as possible. Many vessels then seek the naturally protected adjacent harbor of Porto Bello.

A prominent feature of Limon Bay is the artificial point or jetty head known as Cristobal Point. This was built by the old Panama Canal Company of material excavated from the canal or taken from other points, with its surface brought to about five feet above sea level. It is founded largely upon a coral bank which originally stood at about sea level. Its margin is protected by a rough revetment of fragments of the country rock of small size and concrete blocks a meter (3.28 ft.) cube. This artificial point projects about 1,300 feet into the bay from its easterly side. Recent surveys show that the bottom of all that part of the bay west and north of Cristobal Point is formed largely of mud from 15 or 20 to possibly 30 or more feet deep, the depth of water in the bay opposite being about 28 feet.

The fact that the old Panama Canal Company made the course of the approach channel a tortuous one, with curves of short radius to the entrance of the canal immediately south of and under the protection of the point, indicates the necessity of protecting the entrance of the canal from storm waves. The peculiar formation of the bed of the bay west and north of the jetty indicates that waves and sea currents may, unless checked, produce undesirable or even serious changes in the bottom at a depth of 30 feet and less.

As ships may wish to enter the canal at any time, the terminal harbor must offer safe entrance to it any day in the year and under all conditions of weather. In view of the experience with northers ever since the harbor of Colon has been frequented by shipping it is imperative that this terminal harbor should be so designed and constructed as to protect the dredged approach channel, both against the storm waves and the resulting currents which would otherwise tend to fill the channel. Without such ample protection it is practically certain that the dredged approach channel in the bay of Limon would be filled by sediment during one such norther as that of January, 1905, which was witnessed by three members of the Board. There should also be afforded ample anchorage ground within the protected harbor, with the requisite room for maneuvering.

To enable vessels to enter or leave the harbor at all times, even during severe northers, the channel should have the same direction as the winds during such storms, which are almost always from a point slightly west of north. A vessel entering or leaving this channel in a storm would therefore have the wind ahead or astern and without any wind abeam to complicate the navigation

of the channel. It is for this reason that the Board has proposed a straight entrance channel nearly parallel to the Colon shore and united at its southerly end by a curve of large radius with the axis of the canal near Mindi, as laid down by the French company.

If a line be drawn due west across Limon Bay from Cristobal Point, behind which is found the inner harbor leading to the canal near the mouth of the Mindi, the depth of 28 feet will be found on this line at mean low water throughout the greater part of its length, and it will be seen that the water loses depth at nearly a uniform rate from that point to the shallow mud beach at the southerly extremity of the bay. To the seaward of this line the depth increases quite uniformly to 40 feet about one mile north of Manzanillo Point light.

After much consideration of all the conditions bearing upon the construction of a safe and commodious harbor, the Board provisionally adopted two converging breakwaters, one extending from the beach to the easterly of the light-house in a northwesterly direction one mile, to a point where the low-water depth is at least 40 feet and a short distance westerly of a small reef; the other starting from a point about 3,750 feet west of Manzanillo light, running also one mile to a point where the depth at mean low water is at least 40 feet, so placed as to afford an entrance between the extremities of these breakwaters 1,000 feet in width, the southerly extremity of the latter breakwater to be connected with Great Reef, off Mindi Point, by a breakwater or stone dike two and one-half miles in length. The nearest point of this breakwater to Cristobal Point would also be about 3,750 feet. These breakwaters, therefore, would inclose a harbor area nearly 9,000 feet long from the entrance and nearly 4,000 feet wide for a distance of at least eight-tenths of a mile, within which the depth at low water would vary from 30 to 35 feet. Within the protected harbor a dredged entrance channel 500 feet wide on the bottom and 40 feet deep at low water would lead straight from the entrance between jetties to the canal entrance near the mouth of the Mindi.

At the same time, the inner harbor immediately south of Cristobal Point, and projected as the canal entrance by both the French companies, should be so completed as to afford on its easterly side the necessary coaling facilities, administration offices, and other buildings required by the canal traffic. Vessels entering the outer or main harbor will anchor, if they desire to do so, arrange for payment of dues and their passage through the canal, secure such supplies and make such other communications with the port as may be necessary, then pass to the coaling station, if desired, or proceed directly into the canal.

The breakwaters may be constructed as mounds composed of suitable fragments of hard rock for their superstructures, or blocks of concrete, as may be considered most economical or desirable, but resting upon rubble substructures, which may be of softer material taken from the excavations or from other sources, as the actual construction of the work may make most convenient or economical. The type and cross section of these breakwaters and the general character of the structures would be similar to others which have been constructed on the Atlantic, Pacific, and Gulf coasts of the United States, as at Delaware Bay, San Pedro, on the coast of southern California, and Galveston, Tex.

This harbor as designed, including the ports of Cristobal and Colon, will furnish sufficient accommodations for an indefinite period in the future for the greatest traffic which can now be anticipated for the canal. The Board does not set forth this plan as that which it would necessarily hold to in all details after a more prolonged study and consideration of all the circumstances affecting the construction of such a harbor, but it believes that the accommodations which it would afford will be ample for the purpose and that the amount estimated as its cost is sufficient to cover the construction of a suitable harbor for the Caribbean terminus of the canal should the plan herein described be modified or displaced by another.

The harbor of Ancon.—The harbor conditions at the Pacific terminus are radically different from those found at the Caribbean end, in that no storms ever occur of sufficient magnitude to disturb vessels anchored in the roadstead northerly of the islands of Perico and Naos, the usual anchorage, which is three miles by the present dredged channel to the entrance of the canal at La Boca. Owing to littoral currents from the west this channel requires the practically constant service of dredges in order to maintain a depth of 20 to 22 feet. At the present entrance of the

canal, which is also the mouth of the Rio Grande estuary, there has been built a wharf or pier of steel 1,000 feet long, carrying two railroad tracks and a platform for the exchange of cargo between ships lying alongside the pier and freight cars on the railroad tracks. The foundation structures of this pier, known as the La Boca pier, are steel cylinders sunk to bed rock by the pneumatic process and filled with concrete. Mud and rock have been dredged not only alongside the pier, but over an area in front of it to make a turning basin sufficient for the present needs. The depth of water alongside and in the basin varies from 22 to 25 feet at low water, but, like the entrance channel, must be frequently dredged to maintain this depth.

The bottom of the bay of Panama, at the anchorage off the islands of Perico and Naos, consists of mud mixed with sand, shells, and other materials, and forms excellent holding ground. There are no swells to disturb ships at anchor. There is, however, little depth of water near the shore, and the 30-foot contour lies to the westward and southward of those islands. Deep-water channels approach the islands or this anchorage from three directions, that immediately eastward of the island of Flamenco being probably the best adapted for the approach to the dredged channel leading into the canal.

The tides in Panama Bay are of far greater range than those at Colon, although mean sea level is the same in both harbors. They are very regular. During spring tides the water surface may oscillate between 10 feet above mean sea level to 10 below. During neap tides the range from high to low may not exceed 7.9 feet. Tidal observations have been made at the marigraph station on the island of Naos for many years and they supply data for the statement of the tidal range given above.

The flood tide passes between Naos and Guinea Point, in a direction north-northwest, with a maximum current exceeding two miles per hour. The tide ascends the Rio Grande to a point nearly four miles above La Boca pier and inundates, up to Miraflores, the manglares or low marshes through which the river flows. The period of inflow is short, and after it the water recedes from the swamp with an outgoing current increased by that in the river between two and four hours after high tide. This maximum current is estimated at a little over three miles per hour during the spring tides in that part of the rainy season in which high freshets occur. Under ordinary conditions the current in the Rio Grande during the dry season, or in those portions of the wet season when the rainfall is small, is too slight to have any effect upon the ebb flow of the tide. Between La Boca and the anchorage ground the ebb follows essentially the direction of the dredged channel, with gradually decreasing current, and then turns to the south and southeast beyond Flamenco.

The direction of the present dredged channel is about N. 60° W. It was originally intended by the old Panama Canal Company to give the channel a depth of 30½ feet at low water and a bottom width of about 170 feet, with side slopes of one vertical on three horizontal. The present channel was dredged to a depth of 30 feet below mean tide, and was opened to navigation in December, 1900, since which time it has been in constant service, but this depth has not been maintained. The material taken out in this dredging consisted of mud and silt, some material of vegetable origin, sand, gravel, and, in the vicinity of La Boca pier, a small quantity of rock.

It has already been observed that a littoral current moves from west to east across the dredged channel, causing considerable sediment to deposit. As a consequence of this condition nearly continuous dredging is required to maintain a depth in the channel of 21 to 22 feet at low water. The volume dredged in this manner is about 150,000 cubic yards annually, and sometimes rises to 20,000 or more cubic yards per month. This dredged material is not, except in comparatively small quantities, brought down by the Rio Grande River, but is moved into the channel by the littoral current. The course of that river is short and the volume of its flow far too small to bear a sensible quantity of sediment, nor does the latter appear to be of the character found along the banks of the Rio Grande or in its bed.

There are also other small currents existing in the bay in the vicinity of the entrance channel, and under certain conditions of tide and wind there may be even a little westerly current, but all other movements than that from the west are small and probably negligible in their effects upon the maintenance of the entrance, whether in its present location or on a new line between Ancon and Sosa hills.

If the present location of the Pacific end of the canal from Miraflores to La Boca should be retained it would be necessary to widen and deepen the channel sufficiently to meet the requirements of the ship canal now projected. Remembering that extremely low water may be as much as 10½ feet below mean tide it is obvious that a much deeper excavation will be required to afford the prescribed minimum depth of 40 feet in the harbor approach channel than will suffice at the Caribbean terminus of the canal. The location of the tidal lock will determine the distance inland to which this maximum depth of excavation must be carried. If, as in the former French plans, that lock should be located at Miraflores, a little over four miles from La Boca, the maximum depth of excavation would be carried to that point, but, on the other hand, should the new location for the tidal lock nearer the shore line be adopted the deep-channel excavation would be carried only to that lock.

The French location extending from Miraflores to the anchorage ground in deep water requires much more curvature than is desirable for a canal entrance, and the Board believes that a straight entrance possesses sufficient additional advantages over the old one to justify substantial increase in expenditure to obtain it. A new alignment, therefore, for the Pacific end of the canal and the dredged channel has been adopted, extending from a point between Corozal and Miraflores in a straight course to the new site of the tidal lock between Sosa and Ancon hills, thence with a slight change in direction near the lock directly to deep water off the island of Flamenco. Rock outcrops between Ancon and Sosa hills and that vicinity afford a perfectly satisfactory foundation for this structure. Although the tidal currents might be small in a sea-level section extending from the shore line to a tidal lock at Miraflores, and might only be a source of temporary inconvenience, yet they are undesirable for the navigation of large steamers, and would be entirely avoided by the location for the lock adopted by the Board.

This relocation of the terminal portion of the canal line necessitates the excavation of a materially increased amount of hard rock, which has been included in the estimate of total cost, although as much submarine rock excavation in the vicinity of the islands has been avoided as possible. While there may be a difference of opinion as to the justification for such additional cost in securing a better entrance, there can be no doubt that the alignment adopted by the Board will result in easier and safer navigation for vessels entering the canal from the Pacific, and in much less cost for dredging to maintain it.

The bottom width of the entrance channel leading from deep water off the island of Flamenco to the tidal lock near Sosa Hill will be 300 feet, but the side slopes will depend upon the character of the material to be excavated. Inasmuch as extreme low water of spring tides will occur but rarely, the depth of excavation in this dredged channel is recommended to be but 45 feet below mean sea level. This excavation is sufficient to give at least 40 feet at low water for all but those spring tides having a range of more than 10 feet. As the mean tidal range in Panama Bay does not exceed about 14 feet it is considered that the depth of excavated channel to be provided will never be a source of any inconvenience or any delay whatever for the great bulk of the traffic of the canal, the measure of the maximum inconvenience for ships of greatest draft seeking the canal, if they should be ready to enter it at extreme low water or at about that time, being a total of only two or three hours.

It is evident that the approach channel on this new location may be subject to shoaling by sand moved by the eastward littoral current, as is the present channel. The rock excavated from the new entrance should be deposited along its westerly side so as to form a low dike, completely isolating it from the Rio Grande estuary. This will in no way change the regimen of the latter or of the roadstead near the islands, but it will afford complete protection against the easterly drift of the sediment and thus prevent deposition in the channel. It is possible, though not anticipated, that it may be advisable to form a similar low dike on the easterly side of the channel, and there will be sufficient rock from the channel excavation for that purpose should it be desired. The precise character and amount of these measures of protection for the entrance channel can only be determined in the last instance by observations which may be made during the progress of its construction. It is important to observe that there is no reason whatever to believe that this proposed entrance work will change in any way the character of the anchorage ground north of the islands of Naos, Perico, and Flamenco, which has always been of

so much value to the harbor of Panama and which will in the future be of equal value to the Pacific terminal harbor of the canal.

The principal reason for the existence of the La Boca pier will vanish with the opening of the canal, but even with the new location of the Pacific terminal, uses of value will probably be found for that structure. No better location for shops, small shipways, and other similar and necessary plant can be found near the Pacific terminal than that now occupied at La Boca for those purposes. The requisite depth of water required for the service of these plants in their present positions can always be maintained at small cost, so that their usefulness will in no way be impaired.

The question of the necessity of a tidal lock at the Panama end of the canal has been raised by engineers of repute, but the limited time available to the Board has not permitted the full consideration of this question which is desirable. It is probable that in the absence of a tidal lock the tidal currents during extreme spring oscillations would reach five miles per hour. While it might be possible to devise facilities which would permit ships of large size to enter or leave the canal during the existence of such currents, the Board has considered it advisable to contemplate and estimate for twin tidal locks located near Sosa Hill, even though the period during which they would be needed would probably be confined to a part of each spring tide.

The highest recently recorded range of spring tides which the Board has seen (September, 1905), was 19 feet 9 inches between extreme low and extreme high water, while from 1882 to 1887 the highest amplitude reported was 20.93 feet. With such tides for a brief period at dead low water there would be a differential head of about 10 feet—that is to say, the water in the canal would be 10 feet above that in the bay, while at extreme high water for a correspondingly short period the level of the water in the bay would be 10 feet higher than that in the canal.

At the period of mean tide there would be no difference of level between the bay and the canal, so that during that period of the tide all the gates of the tidal lock could be open, leaving an unobstructed passage for vessels until the approach of the flood tide rendered it necessary for the gates to be closed until slack water would again be reached, and so on for each succeeding spring tide. During neap tides the range is so small that it will not be found necessary to bring the gates of the lock into use. Consequently, throughout the neap period of each tidal cycle a continuously open and unobstructed passage for traffic will be provided through the tidal locks.

If the matter be put into figures for the sake of comparison, it will appear (1) that in the project for the sea-level canal one lock may be required at times at the Panama end of the waterway. For one-half of each tidal cycle of fourteen days the gates may be operated to control a difference of head of an average height or depth of about eight feet for short periods on each tide, while for the remainder the difference of level between canal and ocean will be negligible. For the remaining half of each tidal cycle the gates will be out of operation and the locks will present an open and unobstructed channel, and (2) that in the project for the lock canal six locks or even more will be required for a canal with a summit level 80 to 90 feet above the mean level of the sea; that these locks will have differences of level ranging from about 27 to 35 feet; that their operation will be perennial, they will always be required, and consequently that the menace which they will present to the safe navigation of the canal by large steamers can not be avoided and will be cumulative, i. e., must be multiplied by the number of lockages to which such vessels will be subjected during their passage through the canal.

(c) CROSS SECTIONS OF THE CANAL PRISM.[a]

The cross sections of the prisms will vary with the character of the material excavated. Furthermore, the cross section of the deeply dredged channels at the terminal harbors must obviously be different from those in the canal proper between the shore lines of the Isthmus.

In the judgment of the Board the depth of water in the canal prism and in both of the approach channels of the terminal harbors should not be less than 40 feet, except in the case of the channel in the bay of Panama, where at intervals that depth would not be found during short periods at extremely low spring tides. The depth of 40 feet was therefore adopted by the Board as the standard minimum depth in the canal.

[a] See Plate III for diagram.

The standard bottom width in firm earth, including the dredged portions in soft material between the shore line of Limon Bay and Bohio, was fixed at 150 feet, the side slopes in the same material being taken at one vertical on two horizontal.

In rock the bottom width was taken at 200 feet with side slopes in the channel of ten vertical on one horizontal, i. e., practically vertical. The side slopes above water, as well as below, in firm earth between Bohio and Obispo and south of Paraiso were taken at the inclination of two vertical on three horizontal.

Some modifications of these standard sections were made by the Board in its estimates of quantities of material to be excavated in combined rock and earth sections between Bohio and Pedro Miguel, but not including the Culebra section. At many places throughout this distance the lower portions of those parts of the cuts above the water surface in the canal will be rock overlaid by earth or softer material. In the great summit cut the surface material overlying the rock for a considerable distance in the vicinity of Culebra Hill is clay, which, like all clay, slips easily when wet. When, however, this clay is drained, or otherwise protected from becoming saturated, it stands with satisfactory firmness and gives no trouble. Throughout these combined rock and earth slopes the rock is given a face slope in the estimates of ten vertical on one horizontal and the clay or other material above it one vertical on two horizontal. In the great Culebra cut, which really means the summit divide from Obispo to Pedro Miguel, a distance of seven and one-fourth miles, a special form of section has been taken, although it includes the same elements of slope adopted for other portions of the cuts taken out in the dry. The same rock section for the prism of 200 feet bottom width and with side slopes of ten vertical on one horizontal is carried up to an elevation of 10 feet above mean tide, at which elevation there is provided a horizontal berm 50 feet in width on each side of the canal prism. From the exterior limits of these berms benches are assumed for the purpose of estimate, each 30 feet high, with a face slope of four vertical on one horizontal, the width of the bench at top being 12½ feet. These benches are carried to the upper limit of the rock portion of the cut. This makes the average or mean slope of the rock three vertical on two horizontal. The clay or other soft material overlying the rock is given the same slope of one vertical on two horizontal already described.

It is believed by the Board that the estimated volume based upon these side slopes is ample. It is probable that large portions of this summit cut, composed of harder rock than the indurated clay which forms the material classified as soft rock, will permit of faces having a slope of four vertical on one horizontal to be taken out much higher than 30 feet. It is further believed that there will be little sliding of these benches, assumed in the computations of quantities, so that the volume taken out of the great summit cut is much more likely to be less than that estimated than in excess of it, especially as a contingent margin has been added to all items of cost.

The materials classified as soft and hard rock have been exposed with surfaces fully as steep as four vertical on one horizontal ever since the old company ceased work in 1889, a period of sixteen years. Furthermore, these slopes and others equally steep produced by the excavation made by the new French company have been under the personal observation of two members of the Board throughout the past six years, and under the daily observation of another member for over a year. During this time the effects of weathering have been small, soft rock as well as the hard having stood without sensible slipping or other deterioration. In fact, it is the result of extended experience with these steep faces both in Central America and on the Isthmus that the steeper the faces stand without crushing at their lower portions the less weathering and wash from the tropical rains will occur. It is therefore highly desirable to finish these slopes in as high benches and with face slopes as steep as practicable.

Very few slips of rock have occurred in the deepest portions of the Culebra cut since it was first opened. They are small and have been of such rare occurrence as not to affect the correctness of the preceding observations. The cross sections of the approach channels to be dredged in the harbors of Colon and Panama have been described under "Harbors."

It is believed by the Board that the cross sections of the prism for all parts of the canal from deep water to deep water are well adapted to meet the requirements of the law under which work

on the canal is now prosecuted, and that they are sufficient to accommodate ships of the deepest draft now afloat and which may be reasonably expected for the future. It is further believed that the conditions assumed, especially for the great divide cut, are such as to make the estimated total quantities larger than the quantities which will be actually excavated.

(d) ESTIMATE OF COST.

The unit prices to be applied to the various items of work entering the completion of a sea-level canal have been formulated by the Board after most careful deliberation upon all the conditions affecting the actual prosecution of the work, including climatic effects, inefficiency of available labor, the distance of centers of supplies, the present condition of the various incomplete excavations, the general experience of the Isthmian Canal Commission since its creation, and other influences peculiar to the circumstances which will surround the execution of work in the field to its completion. It has been the intention of the Board to make these prices liberal, so as to remove as far as possible any probability of the ultimate cost of the work being greater than that estimated, and it is believed that they are sufficiently liberal to accomplish that purpose.

It will be observed that they pertain to methods and material which have been well tried in engineering construction and do not rest upon anything of an experimental character, as it is the judgment of the Board that nothing should be included in the proposed plan other than that which has been justified by engineering experience with work as nearly similar to that contemplated in this project as possible. A complete schedule of these unit prices will be found in Appendix R.

The Board has taken account of and given due weight to the fact that vast improvements in mechanical excavating devices have, in the past few years, been made and their effectiveness demonstrated. The Board also believes that other improvements specially applicable at Panama will be developed and used as the work progresses, as was the case during the making of the Suez and the Chicago Drainage canals, and that these improvements will result in large economies and show that the unit prices are much too large; but in fixing these units account has been taken of nothing which has not been tested and justified in actual practice.

Applying the unit prices adopted to the quantities—a tabulation of the main items with a grouping of the smaller items—the following estimate of cost results:

Jetties in Limon Bay	$5,000,000
Excavation and dredging in earth, rock, etc., throughout the canal	183,136,000
Completion of river diversions, formation of dams across tributary streams, regulation of rivers which flow into the canal, etc	3,500,000
Dam across Chagres Valley at Gamboa, with flood sluices, etc	6,000,000
Spillway, with flood sluices, near La Boca	920,000
Twin tidal locks in the Ancon-Sosa saddle	6,000,000
Leading jetties above and below locks	795,000
Relaying track of Panama Railroad	500,000
	205,851,000
20 per cent for contingencies, administration, and engineering	41,170,200
Total	247,021,200

The Board is confident that the Panama Canal can be constructed and completed under the plans set forth and recommended in this report within the preceding total sum of $247,021,200.

There are certain items of cost, such as construction of military defenses, naval stations, government of the Canal Zone, sanitation, light-houses, buoying, lighting, and the provision of tugs, lighters, derricks, dredges, scows, etc., which have not been included. They are common to any type of canal. It was not understood to be the desire of the President that the Board should take into account anything that did not relate to the engineering features of the canal construction, but there is no doubt, in the opinion of the Board, that the expense of maintenance of a sea-level canal will be very much less than for a canal requiring lift locks.

Assuming that the total cost of the Panama Canal, including construction, payments to the French company for the property and franchise, to the Panama Republic for the rights conveyed,

the cost of the Zone government until the canal is open, and other collateral costs, the total possibly reaching $333,000,000, the interest charge on this sum at three per cent would reach $10,000,000. That such an investment would be a safe one from a commercial standpoint is indicated by the fact that the interest and dividends paid to the owners of the Suez Canal last year reached the total of $17,000,000, after paying all expenses of maintenance and operation, also the cost of the extensive enlargements and deepenings which are continually in progress.

(E) ESTIMATE OF TIME.

The time required for the construction of a ship canal across the Isthmus is one of the main elements of the whole subject. If the execution of the work in accordance with any one plan could be completed within a reasonable time while the execution of the work under another plan of equal merit could be realized within a less time, it is clear that the latter plan should be adopted. If, however, there are two plans, both feasible and each involving an amount of work which can be accomplished within a reasonable period, it is clear that the execution of that plan requiring the longer period may be justifiable if the advantages thereby gained are sufficient, or more than sufficient, to compensate for the delay. If the work required under the less desirable plan can be finished within ten or eleven years while that under the more desirable plan would require but two years longer, the small delay in the passage of the first vessel through the waterway might easily be neglected in comparison with the advantages secured under the better plan. It is necessary, therefore, to weigh carefully the significance of the time elements in reaching a conclusion as to the plan of canal to be adopted. In weighing these elements it is further necessary to consider that in the execution of the many locks and dams required for the lock canal, accidents during construction which would defer the opening of the waterway are more likely to take place than in the simpler works of the sea-level canal.

The time required to complete the construction of one or more of the main features of the plan controls the time required for the completion of the entire work, for the obvious reason that the various smaller features may be attacked and completed in detail in less time than would be required for the main or controlling ones. Under well-balanced administration of the work, therefore, the entire canal should be completed when the part requiring longest time is finished. As affecting the question of time for completion, and in marked degree that of cost also, there are two features of the sea-level plan which are of great moment: One is the excavation of the channel through the great divide, amounting to about 110,000,000 cubic yards in a length of about seven miles, and the other the construction of the tidal lock near Ancon-Sosa, having a usable length of 1,000 feet and width of 100 feet, with a maximum lift above mean sea level of 10 feet, this structure requiring over 600,000 cubic yards of concrete and other masonry. These two features have received an extended and careful study.

Inasmuch as hard rock outcrops in the immediate vicinity of the tidal lock site near Sosa Hill the amount of excavation required to secure a suitable foundation is not large and it can be expeditiously completed. The most serious part of this particular problem is to secure and assemble at the site the requisite cement, sand, gravel, or broken and other stone, and the plant required to mix and put in place the great mass of concrete and granite for the masonry portion of the lock. The gates as planned would be of steel, and each leaf would weigh about 275 tons. Their construction, shipment to the Isthmus, and erection in the locks would probably require a period of nearly two years. The Board has estimated that the time required for placement of the concrete and stonework would be four years after the excavation had been completed. It is therefore reasonable to estimate that the entire twin-lock construction, including excavation, concreting, erecting gates, and installing machinery, will require a period of not more than eight years. In estimating the time required it must be remembered that inasmuch as the change of level may be in both directions, up or down, to accommodate extreme high and low stages of tide, two sets of gates will be required in each of the twin locks. The total length of the structure will be not far from 1,300 feet exclusive of the approach works. While these locks are great structures the lifts are comparatively small.

It may be suggested that the Gamboa dam, built to the height of 180 feet above the rock in the deepest place, is also a great controlling factor as respects time, but the Board does not indorse such an opinion. If the dam be entirely of masonry, and allowing amply for interruptions by freshets or floods, the structure can easily be completed in less time than the tidal locks.

The excavation of 110,000,000 cubic yards probably can not be completed in the seven miles of summit cutting within the period of eight years which are estimated to be requisite for the construction of the tidal locks. The excavation at the summit may therefore be considered as the controlling element in the time required to build a sea-level canal. The work in this cut is unprecedented. Great excavations for similar purposes have been made in the Chicago Drainage Canal, at the Corinth Canal in Greece, and in the Manchester Ship Canal. The maximum annual excavations, however, in these works have been 12,500,000, 2,500,000, and 12,000,000 cubic yards, respectively, but in no case was it all steam-shovel work, as it probably will be in the divide cut at Panama. The maximum depth at the Culebra cut from the original surface to the bottom of the canal will be 373 feet and from the present surface 208 feet. The maximum depth of cut in the Corinth Canal was 286 feet, but no other excavation in recent years approaches in depth that proposed at Panama.

The time required to remove this great mass of material, by far the greater part being soft and hard rock, will depend greatly upon the efficiency of the method of operation and the organization of force and plant, all of which must be ultimately the result of most careful consideration of all the elements, including those of climate and character of labor available. It is clear that for the best results the greatest possible amount of work must be done by mechanical appliances and the least possible by manual labor. It is equally clear that the methods of conducting the work, including the control of the plant and force, must be such as will be subject to a minimum of climatic interference and effects of rainfall in the rainy seasons. All parts of the cut must be completely drained, so that the effects of rainfall and springs on the material to be moved may be reduced to the lowest limit.

In considering this part of the Board's work it has taken full evidence regarding this great excavation from not only the present and former chief engineers of the Isthmian Canal Commission, but also from the division and resident engineers who have had the direct charge of the work. The records and plans of the French engineers and committees have been diligently studied. It appears safe to estimate from this evidence that from 80 to 100 steam shovels of the most effective type now in use on the Isthmus can be efficiently employed continually on this work after complete organization. It will require from two to two and a half years to install and put in operation this excavating plant. The independent studies by the Board of the arrangement of railroad tracks and of complete systems of attack at both ends of this summit cut completely confirm the conservatism of the evidence given before it. It is as clearly demonstrable as any estimate of rate of progress and time for the completion of any great engineering work can be that after the full installation of plant not less than 100 steam shovels may be continuously engaged between Obispo and Pedro Miguel until the amount of work remaining to be done becomes too small to afford space for the operation of the whole plant.

The Board recognizes that the removal of the material in the summit cut is in reality a problem of transportation. It is a comparatively simple matter to excavate the material within a much shorter time than that allowed for the work, even on the supposition that all of it except the clay near the surface must be shattered by preliminary blasting. The whole difficulty attending this part of the construction of the canal is attached to the removal of the material from the shovels or other excavators to the spoil banks. This problem of transportation is in reality the substance of the problem of building the transisthmian canal and, in treating this part of the project, the Board realizes and has considered the large amount of railroad track and the extensive transportation organization required for the disposition of the waste material. It is probable, as has been estimated, that not less than three miles of standard track will be required for each shovel employed, making a total of 300 miles of trackage for 100 shovels.

If it be assumed that 100 shovels are available for continuous work, there being a sufficient surplus above that number undergoing repairs whenever necessary to maintain the working

complement, it can be demonstrated that as much as 20,000,000 cubic yards of material classed as rock may be annually removed from the summit cut. This estimate is based upon an average number of working days of not more than 20 per month throughout the year, which is an underestimate on the basis of the experience of the French companies and of that which has accrued since American occupation began, in May, 1904. In this estimate the capacity of one shovel is taken as materially less than would be justified by the actual operations of steam shovels in the Culebra cut during the past year, both in wet and dry seasons. Furthermore, it has been supposed that the working day is to be but eight hours long and that one shift only of laborers would be employed per day, whereas it is perfectly feasible to work two shifts in twenty-four hours during the greater part of the year and possibly during the entire year. Using these estimates for the period of what may be assumed to be the maximum annual output in the Culebra cut, and allowing at least two and a half years to attain this maximum rate at the beginning of the work and a period of not less than three years for a decreasing output in the more contracted space in the lower portions of the cut during the closing period of operations, it is found that the entire quantity of 110,000,000 cubic yards of material in the divide can be removed within ten years. (For time curve illustrating practicable excavation of Culebra cut, see Plate XXXI.)

Although the preceding estimate of time has been based upon ample allowances for the effect of the rainy seasons, for the low grade of labor available on the Isthmus, and for climatic conditions in general, the Board has added about 25 per cent to it for other contingent causes of delay, either similar to those already provided for or of any other character. It is therefore the judgment of the Board that a ship canal on the sea-level plan outlined in this report can be completed within a period of time not exceeding twelve or thirteen years.

(f) IMPORTANT CONSIDERATIONS.

A map of the world or, still better, an ordinary terrestrial globe presents at a glance the reason for the construction of the Panama Canal, such map or globe being of itself sufficient to indicate what the status of the waterway will be, and to show that the canal will provide the one great maritime highway of the West—not between seas, but between oceans; not for countries, but for continents.

The vastness of the interests to be served by the canal, many of which interests now wait for their development on the construction of the waterway, demands that the canal shall, when opened for traffic, be of the type which will most perfectly fulfill the purposes which the waterway is intended to accomplish.

First and foremost it is essential that the Panama Canal shall present not merely a means of interoceanic navigation—it may be said that any type of canal would enable vessels to pass from ocean to ocean—but a means of *safe* and *uninterrupted* navigation, on which no special hazards will be encountered by and no vexatious delays will be occasioned to the vessels which will traverse it. It is therefore evident that the canal ought to be formed in such manner that the course thereof shall be free from all unnecessary obstructions, and that no obstacles should be interposed in that course, whether temporary or permanent, which would by their very nature be an occasion of peril and of detention to passing vessels, and more particularly to vessels of the great size which the Panama Canal is (in accordance with the provisions of the law of Congress) designed to accommodate.

The Board is of opinion that this consideration should be of determinative force in respect to the type of canal to be adopted, and that it should lead to rejection of all proposed plans in which lift locks, whether few or many, form the principal or dominating features, and consequently to the acceptance of the sea-level plan as the only one giving reasonable assurance of safe and uninterrupted navigation.

It is not suggested that a maritime canal with locks forming the essential feature is an inherently unsafe system of navigation, for experience has not only demonstrated the contrary, but also that the matter is one of degree. A navigation with locks of small size capable of passing the ordinary commercial steamers may be made reasonably safe, while a maritime waterway with locks of the dimensions which the Board has considered to be necessary in order to

meet the requirements of the Spooner Act might be and is thought to be so unsafe for the passage of the great seagoing vessels contemplated by that act as to be altogether beyond the limit of prudent design for safe operation and administrative efficiency.

In the course of the proceedings of the Board it transpired that during the last nine years three accidents arising from collisions between steamers in transit and the lock gates, and resulting in each case in dangerous damage to these gates, occurred in the St. Marys Falls Canal; and also that three accidents arising from the same cause and having the same result occurred in the Manchester Ship Canal in England.

Several of these accidents were so serious that disastrous consequences were escaped by a narrow margin only. It is practically certain that if the locks upon which these accidents took place had been of the dimensions and had controlled the great differences of level contemplated for the locks of the Panama Canal, not merely serious accidents but disasters would have followed in perhaps all these cases, throwing the whole canal out of operation for a period which can not be estimated, and also wrecking the vessels in the path of the resulting flood, while the cost required to repair the damages is not within the limits of reasonable computation.

The three accidents at St. Marys Falls Canal occurred within a period of nine years, where there is only one lockage of about 20 feet. If six locks should be adopted in a plan for the Panama Canal, each having a lift of 30 feet or more, as has been proposed in several projects, it would not be unreasonable, with an equal number of vessels, to look for six times the number of accidents in the same period of time, which would be at the rate of two per year. If groups of locks should be arranged in flights, as has also been proposed in some projects, the imminence of disastrous accidents would be greatly enhanced, as would be the amount of damage to the structures and to the vessels involved. Indeed, it is highly probable that the grave disaster of a great ocean steamship breaking through the gates of the upper lock and plunging down through those below might be realized.

It is the unqualified judgment of the Board that the United States Government should not construct an interoceanic waterway to accommodate the commerce of the world exposed to hazards of this sort. These conditions become even more serious when it is contemplated that this canal is to be used for strategic purposes, and therefore for the interoceanic transit of vessels of war of the United States Navy.

Consideration of the growth in size and weight of battle ships during the last ten years—and of the fact that this growth is still progressing—leads to the inevitable conclusion that in the not distant future armor-clad vessels of a beam of 90 feet and with a displacement of 25,000 tons may be expected. The dimensions adopted by the Board for the canal prism and for the lock chambers would admit of the passage of these vessels.

Argument does not seem to be required to emphasize the necessity of avoiding the process of locking these ponderous and unwieldy ironclads up or down in the Panama Canal. The difficulty of handling them in the most favorable circumstances is notorious, while in the operations required for raising them in one series of locks and for dropping them down in another series the difficulty would come so perilously near impracticability that in the opinion of the Board no scheme involving it should be accepted.

As there is no maritime canal in the United States or about its borders it is natural to regard the navigation of the St. Marys Falls Canal as exhibiting conditions practically parallel to those which would exist in the Panama Canal, but inferences drawn upon such a basis may be greatly misleading. The lock in that canal has been so successfully operated and its administration has exhibited such gratifying results that there is danger of forgetting that it is located in an environment of a highly special character. It is now a marked feature of the navigation route of the Great Lakes. The masters of the vessels passing this canal and lock are therefore familiar not only with every detail of the short canal in which the lock is located and of the lock itself, but also of every circumstance of its operation. They pass to and fro with their ships every two or three weeks during the period of navigation, so that the vessels which the lock serves are almost fixed features of a daily routine from which there is little or no variation. Entrance to and exit from the lock becomes by constant familiarity a routine performance in which constant repeti-

tion leads to a degree of skill and safety which can never be attained in a maritime waterway like that of the Panama Canal, serving the commerce of the world, carried in vessels whose masters would come in contact with the physical conditions surrounding the locks and the regulations governing their operation at rare intervals only, and whose crews would be absolutely strange to every feature of this canal service. Under such circumstances any variation from the simplest and plainest conditions of navigation would necessarily be a source of grave danger and likely to lead to serious accident. Again, the canal navigation at Sault Ste. Marie is closed by ice for three or four months each year. Then the locks are or can be pumped out, the gates and all other mechanism examined and repaired or replaced; but there will be no such annual period of idleness for similar overhauling at Panama.

It has already been shown in this report how seriously the existence or nonexistence of locks may affect the safety of this canal navigation. Those considerations will not be repeated here, but it should be observed that the ease with which vicious enemies of all classes may destroy locks by small quantities of high explosives, or even ram lock gates with a passing ship in an apparently innocent manner, or produce other similar damage to locks, might actually put the control of a canal with lift locks in the hands of such an enemy at a juncture when its maintenance of operation for the passage of naval vessels or for other strategic purposes might be of the utmost necessity to the United States Government.

It is true that a sea-level canal or any restricted waterway may be closed by accident, as by a vessel stranding or sinking. Such an obstruction would be temporary only, as it could be removed in a few days, even if the wreck had to be blown up, as recently occurred in the Suez Canal, an incident mentioned elsewhere in this report. Such an accident is not to be compared with those greater and more far-reaching, resulting in the destruction of the lock gates, the drawing off of the water from the summit level, and the possible serious damage to the canal prism.

It may be argued that the objections to which we have referred as existing to the employment of lift locks apply also to the sea-level plan in which the construction of tidal locks at or near the Pacific terminus is a feature. In reply it may be conceded that the argument is at first sight a fair one and that due weight should be given to it; but while it is clear in any case that one obstruction in the course of a maritime highway would be preferable to six or eight, the difference between the functions of any lift lock in the lock-canal proposal and those of the tidal locks in the sea-level plan should be clear to any impartial critic.

The tidal lock is for regulating purposes only, and the reason for its introduction is due to the natural circumstances which exist, there being practically no tidal range in the bay of Limon, at the Atlantic end of the canal, while in the bay of Panama, at the Pacific terminus, the range at high spring tides is more than 20 feet.

Much has been said in the projects submitted to the Board about the advantages of lake navigation in the great reservoirs or lakes which it has been proposed to create by dams across the Chagres on the one side of the Isthmus and across the estuary of the Rio Grande on the other. Extended experience in the navigation of maritime canals on the continent of Europe and in Great Britain has shown that this advantage is largely imaginary, for it has been found in such canals, with prisms of much less dimensions than those recommended for this route, that steamers of the largest size which they can accommodate may steam through them at speeds of about six miles per hour without any real difficulty or danger. Such is the case in the Suez Canal and the Manchester Ship Canal. As a matter of fact, throughout the greater part of the Panama Canal traversing the proposed lakes the actual channels would have submerged banks, necessitating buoys, and within which the speed of vessels would not greatly exceed that possible in the sea-level canal.

It must also be observed in making a comparative consideration of the lock and sea-level types of canal that the locks in the former constitute a restriction or limit to the capacity for traffic of the waterway in which they are found, i. e., they are in a substantial measure obstructions to navigation. There is a limit to the number of lockages per day which may be made, perhaps not exceeding ten per lock or twenty per pair in any of the lock plans hitherto

considered. The maintenance and operation of locks is also costly. If of such great dimensions as those considered necessary by the Board under the Spooner Act, they require the installation, maintenance, and operation of an extensive power plant for the working of the gates. It is not easy to estimate what the annual cost of maintenance, including renewals and operation, of these would be, but, using the estimates of the Isthmian Canal Commission of 1899–1901, it is probable that the annual cost of operation of the six locks contemplated in the projects brought before the Board would be about $525,000. This annual charge capitalized at three per cent would make a sum of $17,500,000 to be added to the cost of the lock canal. The corresponding item in the sea-level plan would be the capitalized annual cost of operating the tidal locks near Panama.

The comparative ease and economy of enlarging the prism of the sea-level canal to accommodate any additional demands of the future must be given the weight which properly belongs to it. The operations which have already been conducted so extensively in enlarging the prisms of the Suez and Manchester Ship canals, and which are now about to be undertaken at the Kaiser Wilhelm Canal at Kiel, show that such operations may be required. The facility with which work of that character may be done in a sea-level waterway where there are no lock structures constitutes a material advantage.

It has already been stated as the opinion of the Board that the time required for the construction of the Panama Canal with a summit level at 60 feet above mean sea level will at best be only two years less than required for the construction of the sea-level canal. But as affecting this question of time, it should be observed that accidents during construction leading to an extension of the time required to complete the canal would be more likely to occur in the more numerous structures involved in the building of the lock canal than in the works for the sea-level canal. It has further been shown that the difference in cost between the two plans will not exceed about $71,000,000 in favor of the former, which must be reduced by the capitalized cost of the maintenance and operation of locks and by the cost of the overflowed lands, as before stated.

It is seen, therefore, that the lock design has inconsiderable advantage either in time of realization or ultimate cost over the one recommended by the Board for adoption by the United States Government, which possesses all the advantages of practically indefinite capacity for traffic, besides a degree of safety and uninterrupted operation which can not be approached by any lock plan.

Did a canal now exist of the widths proposed, but limited in depth to 35 feet, it would accommodate all existing shipping. By restricting the depths in the prisms (but not in the locks), as suggested but not recommended, the channel could probably be opened in a year or two less than if constructed at first to full depth, and the saving in cost would amount to about $17,000,000. When it should be decided to take out the other five feet in order to accommodate vessels of a greater depth, that could readily be done at some increase of cost over what would have been incurred if made originally at the full depth of 40 feet.

The Board desires to emphasize the fact that in its knowledge no great enterprise in connection with transportation, whether it be a canal, a railway, a harbor or docks, or similar work, has ever yet been completed of such size or proportions that subsequent enlargement did not become necessary. The Board is therefore of the opinion that in this particular case the United States Government should construct this great artificial waterway of such type and dimensions as to give it at the outset the maximum capacity that seems likely to be required, guaranteeing the greatest facility of operation, and leaving the canal as constructed with ample provision for a reasonable future increase of traffic and in condition for most speedy and economical enlargement in response to the future demands of commerce, without the undoing of any construction.

It is the belief of the Board that the essential and the indispensable features of a convenient and safe ship canal at the American Isthmus are now known; that such a canal can be constructed in twelve or thirteen years' time; that the cost will be less than $250,000,000; that it will endure for all time.

The Board does not believe that a provisional treatment of this great question would yield results which would be satisfactory to the American nation or advantageous to American commerce, or that such treatment would be in consonance with the increase of population, of trade, and of wealth which will surely take place during the next half century in the Western Hemisphere.

For all these reasons the Board recommends that the sea-level plan be adopted for the Panama Canal.

Mr. Quellennec's indorsement of this report is to be considered in connection with his statements qualifying his vote as recorded in the minutes of the nineteenth and twenty-fifth meetings.

Respectfully submitted.

GEO. W. DAVIS.
WM. BARCLAY PARSONS.
WM. H. BURR.
WM. HENRY HUNTER.
AD. GUÉRARD.
EUGEN TINCAUZER.
J. W. WELCKER.
E. QUELLENNEC.

MINORITY REPORT.

The undersigned, a minority of the Board, concurring with much of the preceding report, dissent from the preference expressed for a sea-level canal.

We believe a lock canal the better one for the United States to construct, for the following reasons:

1. Greater capacity for traffic than afforded by the narrow waterway proposed by the Board.
2. Greater safety for ships and less danger of interruption to traffic by reason of the wider and deeper channels which the lock canal makes possible at small cost.
3. Quicker passage across the Isthmus for large ships or a large traffic.
4. Materially less time required for construction.
5. Materially less cost.

The studies of a lock canal by the Board, and for the Board by its committees, embraced a number of projects with summit levels varying from 30 to 90 feet above mean tide (which will be hereinafter referred to as elevation 30, elevation 90, etc.), with duplicate locks having usable widths of 95 and 100 feet, and usable lengths of 900 and 1,000 feet, located at various places, and with the summit level maintained on the Atlantic side by dams at Mindi, Gatun, Bohio, or Obispo. The projects of Mr. Bates, with summit levels up to elevation 97, of Major Gillette, with summit level at elevation 100, and of Mr. Bunau-Varilla, with summit level at elevation 130, were also considered. The Board selected for comparison with the sea-level project a lock canal with summit level at elevation 60 and with locks having a width of 100 feet and usable length of 1,000 feet, which is described in the report of the Board.

The undersigned are of opinion that there are several variants for lock canals which should have preference over the sea-level project, consideration being given to facility and safety of transit, and time and cost of construction; and that, for reasons which follow, locks of the smaller dimensions noted above will adequately meet all probable demands for a long term of years. We present for comparison with the project preferred by the Board, to be considered later, a project with summit level at elevation 85 maintained by a dam and duplicate flights of three locks at Gatun. This is recommended for adoption, General Abbot preferring a lower dam with duplicate flights of two locks at Gatun, supplemented by a dam and duplicate single locks at Bohio, raising the summit level to elevation 85, as before.

THE LOCK-CANAL PROJECT RECOMMENDED.

This project is a modification of the one adopted by the Isthmian Canal Commission of 1899–1901, the modifications being due in part to the requirement for greater dimensions imposed by the act of Congress approved June 28, 1902, called the Spooner Act, and in part to data collected within the last two years, which make it feasible to design a much better canal without increased cost. The elevation of the summit level is practically the same as in the earlier project. Unfavorable developments at the site of the proposed Bohio dam and the existence of more favorable conditions at a site nearer the Atlantic, together with important incidental advantages, have led us to recommend the latter. On the Pacific side the terminal lock is placed at Sosa, instead of at Miraflores, for reasons which will appear further on.

(a) THE COLON ENTRANCE.

Commencing the description at the Atlantic end, the plan of the Board for a breakwater in Limon Bay is, with only a slight change, adopted for purposes of estimate. The change consists in swinging the long westerly line out from the shore at Mindi Point far enough to permit the

channel (500 feet wide and 41 feet deep at mean tide) to be made through the easily dredged earth outside the point, instead of inside the point where there would be much expensive rock excavation. The breakwater and channel as modified will be extended to the head of the bay. It seems possible that the breakwater may be dispensed with wholly, or in part, and the channel widened to 1,000 feet or more, to the advantage of navigation and with a reduction of cost.

The Board's plan of harbor and canal entrance, however, is much superior to that of the French company, as it provides a safe and easy entrance at all times. The distance from the head of the breakwater to the shore line near the mouth of the river Mindi is 4.55 miles. From this point the 500-foot channel is to be continued 2.6 miles farther, to the locks at Gatun.

(b) THE GATUN DAM.

The controlling feature of the project with summit level at elevation 85 is the earth dam across the Chagres at Gatun. The object of this dam is to form a great reservoir, or inland lake, in which the floods of the Chagres will be received and from which the surplus water will be discharged through sluices and the height of water in the reservoir regulated. Lake Gatun will be about 110 square miles in area and will form the summit level of the canal. The lake will also serve to impound water for lockage and other purposes during the dry season and to give free, open navigation in a broad waterway all the way from Gatun to Obispo.

Every lock plan heretofore recommended for a Panama Canal has included a dam across the Chagres, thereby providing for lake navigation for a portion of the distance across the Isthmus. All of the official reports have recommended that the dam be placed at Bohio, where the valley is narrow, but Gatun has also been mentioned as a site which would be advantageous if the feasibility of building a dam and locks at this place at a reasonable cost were established.

Since the United States has taken charge at the Isthmus, the Isthmian Canal Commission has had many borings made at and near these two sites. Those at Bohio, which are especially complete, show a greater proportion of water-bearing porous material than had previously been found. The maximum depth to the rock on the most feasible line for a dam at this place is 165 feet below sea level.

The borings made prior to September, 1905, at and near Gatun showed nearly everywhere an admixture of sand with clay and impervious material, with a maximum depth to rock of 204 feet below sea level. Many of the borings, even those at considerable depths, encountered shells, wood, and vegetable matter, all tending to show that the material had been deposited in currents too sluggish to transport gravel and other coarse material.

The borings were "water jet" or "wash drill" borings, made by first driving, when necessary, an iron pipe (known as a casing) having an inside diameter of two or two and one-half inches, and then inserting a smaller pipe through which a jet of water was forced, washing the material in the larger pipe through the annular space between the two pipes to the surface of the ground. It was characteristic of these borings, and also significant, that in many cases it was not necessary to drive any casing; or, if one was driven, it was not necessary to drive it to the full depth, as the material contained enough clay to sustain the sides of the hole without the casing.

Of 27 borings made before September with reference to the location of a dam at or near Gatun, no casing was used in thirteen holes; in three other holes the length of casing did not exceed 20 feet, while in the remainder the length of casing ranged from 28 to 101 feet, but in no instance was the casing driven much more than halfway down to the bottom of the hole.

The depth to rock was shown to be so great, both at Bohio and at Gatun, that it would be costly and difficult in either case, if not impracticable, to excavate to the rock or to provide any efficient cut-off or stop-water extending from the surface of the ground to the rock; and if a dam were to be built without such cut-off the borings showed clearly that there would be less seepage beneath a dam built at Gatun than at Bohio.

In addition to the borings, the Commission had caused topographic surveys to be made at the site of the dam, which showed what was apparently an excellent site for locks on the high ground back of Gatun, and a suitable site for a diversion channel for conveying the water of the

Chagres during the construction of the earth dam and for regulating works to control the discharge of surplus water from the lake to be formed by the dam.

Few borings had been made at the exact site selected for the dam, and none had been made at the sites selected on the high lands for the locks and the regulating works. The Commission was therefore requested by the Board to have some additional borings made, both on the high lands and in the valleys, and also some additional topographic surveys.

The location of all borings is shown on the map of the Gatun dam site, Plate XI, and the borings on a line across the valley at the dam site are shown on Plate XII.

It will be noticed on Plate XII that there are two deep depressions or gorges in the rock, which have been filled with alluvial material. The deepest boring penetrated this material 258 feet before striking rock. The lower 50 to 60 feet of the material in the deepest gorge was found to be for the most part porous sand and gravel, which was undoubtedly deposited at a time when the currents through the gorge were swifter than existed when the upper 200 feet of the alluvial material was deposited. In the upper 200 feet some of the later borings show fine sand, while other borings near by show clay at the same depths, indicating, as do previous borings, that the upper 200 feet is practically impervious material. There was an outflow from several of the borings which penetrated the gravelly material in the bottom of the deep gorge, although the tops of the casings were above the surface of the river. This showed conclusively that there was no near connection with the bed of the river; in other words, that the material covering the sand and gravel was impervious for a long distance.

A sample of the material washed from the ground during the boring operations, which had been collected in a pail without allowing any of the fine material to escape, was shown to the Board during its visit to the Isthmus. This sample showed material of sizes varying from sand to the very fine particles of clay which settled last and formed an impervious film over the surface of the coarser material deposited in the bottom of the pail.

The samples of sand which had been obtained up to the time of the visit of the Board were fine, much more so than samples from borings at the Bohio site.

We believe as a result of the borings which have been made that if a large earth dam were to be built at Gatun, as indicated upon the drawings, there would be no appreciable seepage under the dam, owing to the practically impervious nature of the material on which it would rest and to the fact that the more pervious material found at the bottom of one of the gorges in the lower 50 feet is covered by a blanket of practically impervious material 200 feet thick.

The borings on the high ground, at the site of the locks, the regulating works, and elsewhere, showed generally soft clay to a depth of 20 to 30 feet below the surface, where indurated clay—a soft but compact rock—was found.

In making the design of an earth dam at Gatun, it was thought best to provide a dam which could not be destroyed by any of the forces of nature, and which could only be destroyed by making excavations which would require a large force working for a long time.

The cross section of the dam has been given the unprecedentedly large dimensions shown on Plate XIV. Its top is 50 feet above the water level in the lake and 100 feet wide; at the water level the distance through the dam is 374 feet, and at sea level the corresponding distance is 2,625 feet, or one-half mile.

It is intended that the downstream toe of the dam for about 200 feet shall be composed of rock obtained from excavation in the canal prism, so that if there should be any seepage of water through the dam there will be material at the toe which can not be washed away. The lower part of the dam, up to elevation 50, or even to elevation 80, is to be made from material dredged from the canal between the Gatun locks and Limon Bay, pumped by a suction dredge into the dam, the process being similar to the sluicing process employed in the construction of some important dams in the western part of the United States. By this process it is feasible when using a material like the alluvial material at Gatun, which contains both coarse and fine material, to separate the two and to deposit the coarser material toward the downstream slopes, forcing the finer material to the extent desired into the upstream portion of the dam. An embankment built in this way will be water-tight.

For the upstream slope, rock obtained from canal excavations will be dumped as riprap, care being taken to provide an ample thickness at and near the level where the dam will be exposed to wave action.

The portion of the dam above elevation 80 will be built of impervious material to a few feet above the water level, and at higher levels may be made of either earth or rock, as most convenient. It is expected that for the upper part of the dam, spoil from the Culebra cut will be used.

While earth dams are in common use, and in many cases support greater heads of water than would exist at the proposed Gatun dam, it will still be argued by many that in a great work like the Panama Canal nothing should be trusted but the most massive masonry dam on a solid rock foundation. At Gatun the rock lies at so great a depth that a masonry dam thus founded is impracticable, and without such foundation a masonry dam would be most unsuitable. It seems desirable, therefore, to enter to some extent into the discussion of the stability of the proposed earth dam.

STABILITY OF AN EARTH DAM.

It is obvious that if a dam of this kind is to fail, some part of its length must be pushed away bodily, or the earth of which it is composed must be carried away by currents of water. There are no other natural forces which can materially affect the stability of the dam.

The horizontal pressure of the water in the lake per linear foot of dam is less than one sixty-third of the weight of the dam per linear foot, a pressure so small that it is obvious that it can not move the whole mass, and there is left, therefore, as the only way in which a dam of this kind may fail, the carrying away of its parts by a current of water.

The currents of water requiring consideration are those resulting from the action of the waves, from the rainfall, or from seepage through the dam.

The feasibility of protecting the face of the dam from the action of waves will hardly be questioned. The effect of the rainfall can easily be provided for, particularly on the main downstream slope, which falls but one foot in twenty-five.

It is impossible for water to flow over the top of a dam that is raised 50 feet above the water level, and if the dam and the underlying material were strictly impervious there would be no water from the lake passing through it. On the other hand, if the material in or under the dam is somewhat pervious, there will be some water passing through which will appear at the surface, either immediately below the dam or toward the lower portion of the downstream slope.

The amount of water which will pass through somewhat pervious material in or under a dam depends upon the relation between the total head and the distance through the dam, and not, as is sometimes assumed, upon the total head against the dam.

If two dams are built under similar conditions, except that one has a thickness five times as great as the other, then there will be at the dam having the greater thickness only one-fifth as much seepage as at the other; that is to say, other things being equal, the seepage through a dam will be substantially in proportion to the depth of water against the dam, divided by the distance through the dam, giving what may be called the hydraulic gradient or slope of the line of saturation, which in this case does not exceed four per cent.

There have been many experiments on the vertical and horizontal filtration of water through various kinds of materials and with various hydraulic gradients. Some of these were made at the Lawrence Experiment Station of the Massachusetts Board of Health and others were made at the Wachusett reservoir of the Metropolitan Water Works, in Massachusetts, in connection with the construction of a dam similar to that proposed at Gatun. These experiments were made with materials of uniform character, through which more water would filter than through materials containing fine and coarse particles of the same average degree of coarseness, such as those found at the site of the Gatun dam, and they furnished results which confirm the statement already made that there would be no appreciable seepage under this dam.

If, however, a condition which *does not exist* be assumed, and all of the alluvial material beneath the embankment of the dam were considered to be a clean and reasonably uniform sand of

medium size, the total amount of filtration would then be for the whole length of the dam only about 10 cubic feet per second. Even this amount, which is much larger than would actually exist, is insignificant, and is less than one-half of one per cent of the water supply available in the driest season.

Few engineers who have been connected with the filtration of city water supplies would hesitate to provide works which would permit the amount of water above stated to rise to the surface without carrying with it any of the earth, because they have a much more difficult problem in connection with the downward filtration of water, where the works must be so built that the sand will not be carried down with the water.

The method followed in water filtration is to place coarse stones at the bottom of the filter and to cover these stones with finer and finer stones, and then with coarse sand, in order to retain the finer sand used for filtration. It is a simple operation to build the reverse of such a filter, which will permit the water to rise from the ground without carrying the earth with it.

It is not expected that there will be enough seepage through the Gatun dam to require any special treatment, but if there should be it could readily be taken care of by the method indicated, which has already been used with success in connection with a dam built of sand on a sand and mud foundation at Jeypore, India.

Upward filtration occurs frequently in nature, where water comes from springs near the base of hills, often in sandy or gravelly material, without carrying with it any appreciable quantity of earth.

Many small earth dams and levees have failed, owing to a passage being made through them by some burrowing animal, or by the water following some pipe or other structure built through the dam, but in the present case it is not proposed to lay any pipe or other structure through the dam, and a burrowing animal could not burrow through where the shortest distance at the water line is 374 feet.

It seems to be impossible that any of the particles of earth buried in the body of the dam could be moved by a slow seepage of water, except such particles as were soluble, which might, in the course of ages, be dissolved and carried off by the seepage water.

Some of the views held in respect to the movement of material in the body of earth dams are based upon observations of very small dams, and often of those negligently constructed or of a very narrow section, and have no place in connection with a properly constructed large earth dam.

A dam such as the one proposed is very heavy, the weight upon its foundation being about one ton per square foot for each 20 feet in height of embankment. Under the highest part of the embankment the pressure would be six and one-half tons per square foot. It is obviously impossible that with such a pressure upon the material any particles could be moved by the extremely gradual seepage of water through the interstices due to a difference of water level of less than four feet in 100.

Such a dam as is here proposed if not absolutely earthquake proof is probably more nearly so than any other type of dam.

A comparison between the section of the Gatun dam and that of a few existing earth dams is shown on Plate XIV. The San Leandro dam of the Contra Costa Water Company, 120 feet high, which supplies water to Oakland, Cal., is the highest earth dam in the world, and it was constructed in part by sluicing. The Pilarcitos dam, 95 feet high, built in 1866 by the Spring Valley Water Company, which supplies water to San Francisco, is also one of the larger dams, although there are several others of about the same size, which have been successful.

The Jeypore dam is introduced on the diagram because it was built of sand on a foundation of sand, mud, and soil, and at a place where the material is very pervious, so that considerable water filters under and through the dam. It has, however, proved to be stable under these conditions.

The United States Reclamation Service has recently planned an earth dam to sustain a head of 100 feet with a width at the water line less than one-fourth that proposed for the Gatun dam and with a proportionately narrow base.

It will be noted that these dams have a small section in proportion to the depth of water behind them when compared with the Gatun dam.

Earth dams are in such common use, are so generally indorsed by engineers, many of whom prefer them to other forms, that this extended discussion has been given only because the proposed use of earth dams has been unduly criticised in the report of the Board.

The nearest precedent in general design for the Gatun dam is the north dike of the Wachusett reservoir of the Metropolitan Water Works, of Massachusetts, which is two miles long and at the deepest place will have 65 feet of water against it. The highest portion of this dike was built on exactly the plan proposed for the Gatun dam, namely, the fine material of which the dike is composed was deposited on the fine underlying material without the use of either masonry or sheet piling to prevent the filtration of water. Under portions of this dike the depth to the rock is as great as at the Gatun dam.

PLAN OF THE DAM.

Plate XI shows a plan of the dam. Its total length from the locks to the westerly end is 7,700 feet. About midway in the length of the dam there is rising ground in which it is proposed to excavate, as already indicated, a diversion channel through which the Chagres will flow during the construction of the earth dam.

The regulating works, to be subsequently described, will be built mainly of concrete and will be located in part in the diversion channel and on each side of it. On each side of the rising ground referred to, and extending from it westerly to the high ground and easterly to the locks back of Gatun, there will be great earth embankments of the cross section already described, which will together contain 21,200,000 cubic yards of material. The westerly embankment will cross a French diversion channel. The easterly embankment will cross the French canal and the Chagres.

It will be feasible to begin at once the construction of one of the earth embankments, permitting the water to flow through the channel or channels at the site of the other embankment. It will also be feasible to begin at once the construction of the diversion channel, utilizing the material excavated in the embankments of the dam.

In the construction of the dam it is proposed to remove all trees, stumps, and roots from its site and to excavate the surface material to such an extent that the impervious material of the embankment will come in direct contact with the impervious clayey material which is found nearly everywhere in this region; also to do any other work required to cut off the flow through any pervious material which further investigations may disclose. For such work an allowance of $400,000 for all dams has been made in the estimate of cost.

The diversion channel is to have a minimum width of 150 feet and is to be excavated to sea level, or somewhat below it; although the lower part of the channel will be through indurated clay, it is proposed to place in it concrete where required for the protection of the channel or for the regulating works up to sea level, and to build in the channel to an elevation about four feet above sea level the foundations of certain piers and walls, which will remain for a time at this elevation, so that they will form only a slight obstruction to the discharge of flood waters.

After the earthwork of the dam reaches a sufficient height to be beyond all danger of overflow, the piers and walls, which will be above water at low stages of the river, and which will have in them grooves for stop planks, will be built to higher elevations to furnish a ready means of turning the river through half of the diversion channel while the other half is pumped dry to permit the placing of the concrete of the regulating works, and by turning the river alternately from one side to the other the regulating works may be built without special difficulty.

REGULATING WORKS.

The general design of the regulating works is shown on Plate XIII. The central 150 feet of their length, which will be built up from the bottom of the diversion channel, is to be a solid mass of concrete, having its crest at elevation 69. The crest is to be made wide with the downstream slope two horizontal to one vertical, making an unusually strong section.

On the top of the crest, piers eight feet in thickness, grooved for Stoney sluice gates, are to be built 38 feet from center to center, having clear openings of 30 feet. These gates, as proposed, are almost exact counterparts of the gates provided for controlling the flow from the lower end of the Chicago Drainage Canal, but the sills are to be placed 16 feet below the normal water level, instead of 15 feet, as at the Chicago Drainage Canal.

For the whole length of the regulating works the design is the same as the central portion, except that the concrete rests upon the surface of the rock or upon excavations made in the rock, as indicated by the two smaller sections on the plan. The water passing through the central sluices will flow directly out through the diversion channel to the Chagres; that passing through the sluices nearer the ends of the regulating works will be caught by intercepting channels sloping toward the central portion, and will follow the course indicated by the arrows on the plan, flowing toward the central portion and thence out through the diversion channel.

The regulating works are capable of discharging 140,000 cubic feet per second when the water in the lake is not more than one foot above the normal level.

It is thought that in connection with a great lake, such as here proposed, regulating works which can discharge a great quantity of water when the lake is at its normal level are preferable to an uncontrolled overflow spillway which will not begin to discharge water in any considerable quantity until a flood has raised the lake above its normal level.

With the uncontrolled spillway 2,000 feet long, recommended by the Isthmian Canal Commission of 1899–1901 in connection with the Bohio dam, it was estimated that the water in the lake might be raised five feet above its normal level by a maximum flood.

With the regulating works proposed in connection with the Gatun dam it is estimated that the surface of the lake will never be raised by a maximum flood more than two feet above the normal level, and with ordinary floods it would be feasible by beginning the discharge before the flood waters reached the lake to keep the surface from rising to any appreciable extent.

Such sluices as are here proposed would be very objectionable on a river or even at the outlet of a small lake, but in a great lake like that to be formed by the Gatun dam the currents toward the outlet will, under ordinary conditions, be inappreciable, so that the course of any floating substances will be determined by the wind instead of by the current and they will be stranded on the shores; moreover, if, during floods, trees and other drift should be washed into the lake from the tributary rivers, they would not have time, on account of the great size of the lake, to reach the Gatun dam before the flood subsides.

REDUCTION IN COST.

The great quantity of material to be placed in the Gatun dam may cause it to be inferred that a structure at this place adds to the cost of the canal; but it should be borne in mind that the adoption of this site eliminates large expenditures for the canal and diversion channels between Gatun and Bohio. A comparison shows that there is a saving of $11,894,621 in the estimated cost of works by the change in the location of the dam, made up as follows:

Works omitted.

Bohio dam	$6,369,640
Gigante spillway	1,209,419
Canal between Gatun and Bohio	7,643,067
Peña Blanca outlet	2,448,076
Chagres diversion	1,929,982
Gatun diversion	100,000
	19,700,184
Add 20 per cent for contingencies, etc	3,940,037
Total for works omitted	23,640,221

Additional works required.

Gatun dam	$7,788,000	
Panama Railroad diversion from Mindi to Bohio	2,000,000	
	9,788,000	
Add 20 per cent for contingencies, etc	1,957,600	
Total for additional works required		$11,745,600
Amount saved by change in location of dam		11,894,621

The estimates of the cost of the works omitted were made by the Isthmian Canal Commission of 1899–1901.

In the above table it will be noted that the locks have been omitted. The lock site at Bohio adopted by the Comité Technique of the New Panama Canal Company and by the Isthmian Canal Commission of 1899–1901 furnished a rock foundation for only two locks of the sizes then proposed. The requirement of the law under which the canal is being constructed makes it necessary to provide longer locks than can be accommodated with a rock foundation at the Bohio site. Moreover, it was thought desirable to make the lift to the 85-foot summit level with three locks rather than with two, and the Gatun site affords an opportunity for doing this. The three large locks will cost more than the two smaller locks proposed at Bohio.

The adoption of Gatun as a site for a dam not only provides for reduced cost and a better lock site, but, as compared with Bohio, it offers several important advantages. The first of these is a large addition to the drainage area tributary to the summit level and to the amount of water available for canal uses, which is of special value during the dry season; the second is the great increase in the reservoir area, Lake Gatun having almost three times the area of the lake formed by a dam at Bohio; this permits storing water for the dry season and the reception of floods with a maximum variation of lake level of only about one-half of that taken by the first Isthmian Canal Commission for Lake Bohio. A third advantage which will be described more fully farther on is the extension of lake navigation nine and one-half miles toward the Atlantic from Bohio; a fourth is that the Chagres and all its important tributaries will be received into the lake at points so distant from the canal route that no deposit of suspended material will occur along it, and a fifth is that the water discharged from the lake will enter the Chagres at the point where it finally diverges from the canal so that no diversion channels or heavy protecting embankments will be required along the canal line.

(c) WATER SUPPLY OF THE CANAL.

The general subject of water supply for the canal is treated in a paper by Gen. Henry L. Abbot, published as Appendix E of this report, and the present statement will deal only with the main features of the water supply for the project recommended.

It has been shown in the paper mentioned that the volume which would flow into Lake Gatun in the dry season is about two-thirds greater than that into a lake formed by a dam at Bohio, and that the minimum contribution to Lake Gatun, judging from the record of measurements of flow covering a period of fifteen years, is 1,250 feet per second during the driest three months. In order to provide for still drier periods it has been thought advisable to adopt 80 per cent of this volume, equal to 1,000 cubic feet per second, as an entirely safe quantity.

The lake can be safely raised toward the end of the wet season one foot above the normal level, and provision has been made in the design of the canal for drawing the lake three feet below the normal level, so that the contents of the upper four feet of the lake, equal to 12,270,000,000 cubic feet, will be available for water-supply purposes during the dry season.

This quantity will provide a steady flow of 1,577 cubic feet per second for ninety days, making the total quantity of water, after adding the inflow, 2,577 cubic feet per second.

Not all of this water, however, is available, as it is necessary to deduct losses by evaporation and leakage, and it is also convenient to use some of the water to furnish power for operating the gates, for lighting, and for other purposes.

The quantities required for these purposes are given in General Abbot's paper, and have been adopted with only a slight modification of the amount of leakage, due to the smaller size of gates provided by the plan recommended. The amounts are as follows:

	Cubic feet per second.
Evaporation	710
Leakage at gates	240
Infiltration, waste at locks, etc	77
Lighting, power, etc	200
Total	1,227

The item of 200 cubic feet per second for contingencies given in his table has been omitted, because this has been covered by using only 80 per cent of the estimated minimum flow; moreover, the allowance for evaporation is a very liberal one.

The net quantity of water available for lockage is, therefore, the difference between 2,577 and 1,227, equal to 1,350 cubic feet per second.

To determine the number of lockages which this quantity of water will provide for, the following provisions and assumptions have been made:

Intermediate gates are to be provided for the locks at Pedro Miguel and Sosa, so as to give a chamber length of 600 feet, and it is assumed that the intermediate gates will be used for eight-tenths of the lockages. At the Gatun locks intermediate gates would not furnish the same advantages for saving water, as there are three locks in a flight, and they are therefore omitted.

It is further assumed that all ships passing in one direction will use one set of locks, and all ships passing in the other direction another set. On this assumption, the same quantity of water is used whether a ship passes through a single lock or through two or three locks in a flight.

The lift to the normal summit level at Pedro Miguel is 30 feet and at Gatun 28⅓ feet per lock. The quantity of water required per lockage at Pedro Miguel, on the assumption that intermediate gates will be used eight-tenths of the time, is 22.13 cubic feet per second, and the quantity per lockage at Gatun 29.77 cubic feet per second, making a total of 51.90 cubic feet per second.

The net available quantity of water is, as already stated, 1,350 cubic feet per second, and will therefore provide for 26 lockages per day at each lock during the driest three months.

In order to provide for more lockages per day it will only be necessary to store more of the freshet water. The Alhajuela dam, raised to the height proposed by the Comité Technique, would store enough water to provide for fully 27 additional lockages per day.

In order to determine the amount of tonnage provided for by the 26 lockages per day, for which the water supply is sufficient without the Alhajuela dam, it is necessary to take into account the amount of tonnage which will pass through the canal per lockage, and in this connection it should be noted that the full-sized locks will pass two ordinary ships at a time.

The size of the ships passing through the Suez Canal has been increasing from year to year; they averaged 3,163 tons per ship in 1904 and 2,398 tons per ship ten years earlier. The rules for measuring tonnage at this canal, however, give a measurement in excess of that given by Lloyd's net register of about one-sixth.

It seems probable that when the traffic at the Isthmus requires 26 lockages per day, in view of the growth in the size of ships and of the fact that two ships of ordinary size can pass through a lock at the same time, the amount of tonnage per lockage will be as much as 5,000.

The annual tonnage provided for by the water supply, both without and with the Alhajuela dam and on a basis of 3,000, 4,000, and 5,000 tons per lockage, is as follows:

Tons per lockage.	Annual tonnage without Alhajuela dam.	Annual tonnage with Alhajuela dam.
3,000	28,470,000	58,035,000
4,000	37,960,000	77,380,000
5,000	47,450,000	96,725,000

Should it be found necessary in the future to provide for the passage of a still larger tonnage, the Chagres and its tributaries will furnish additional water, which may be stored and subsequently utilized.

(d) THE SUMMIT LEVEL.

As already stated, the summit level will be reached from the level of the Atlantic by means of duplicate flights of three locks at Gatun. The flights being in duplicate give security against serious delays to ships in case one flight is out of use, as it must be occasionally to make the repairs and renewals necessary for efficient work. The facility afforded for repairs by duplicate locks meets any objection that there will be no period at the Panama Canal for repairing gates and other mechanism.

The total length of the lake will be 30 miles, of which 23 miles will be navigated by ships crossing the Isthmus. Its depth will be about 75 feet in the immediate vicinity of the dam, this being maintained with little reduction to Bohio and thence reducing gradually toward Obispo, where the depth of 45 feet will be obtained with but little excavation, the bed of the river being about 45 feet below the surface of the future lake.

For 15.69 miles above the Gatun locks the deep portion of the lake will have generally a width exceeding half a mile, and only a small amount of excavation will be required to provide a navigable channel nowhere less than 1,000 feet wide at the bottom and 45 feet deep. Farther up the lake, as the amount of excavation required to obtain a depth of 45 feet increases, the minimum width of the channel will be decreased, first to 800 feet for a distance of 3.86 miles from San Pablo to Juan Grande, then to 500 feet for 3.73 miles to Obispo, and to 300 feet for 1.55 miles from Obispo to Las Cascadas, where the channel will be further narrowed to 200 feet through the heaviest portion of the great central mass known as Culebra.

From Gatun to Obispo, a distance of 23.51 miles, the banks will be submerged except at a few points. Where excavation is required the side slopes will be one on one in earth and four on one in rock. From Obispo to Las Cascadas the banks will be a little above water for the greater part, and the borings indicate a good quality of rock which will permit nearly vertical sides. The sides should be made smooth for the greater safety of ships. This will give 25 miles of navigation from Gatun to the Culebra cut through channels nowhere less than 300 feet wide, and is about twice the distance for which a similar navigation was provided in the project of the first Isthmian Canal Commission, the improvement being due principally to the extension of the summit level from Bohio to Gatun, but also to some extent to enlarging the channel in the vicinity of Obispo, which can be done without great cost. The broad waterway from Gatun to Culebra really furnishes lake navigation and closely resembles the great navigable channels in many harbors and those through the succession of small connected lakes between Lakes Superior and Huron, called the St. Marys River, where the dredged channels in the shallower waters are 300 to 600 feet or more in width and are traversed by a tonnage of more than 3,300,000 net registered tons per month at a speed limited by regulation to nine miles per hour, a limit found necessary in the 300-foot channels on account of the dense traffic and frequent meetings.

Where changes of direction occur, the outer channel lines of adjacent courses are to be carried to an intersection, although very little excavation is required to accomplish this; the point of the inner angle will be dredged off so that a curve of 8,000 feet or more radius can be laid down wholly within the channel limits. This way of changing direction is illustrated in Plates XVIII to XXVIII, which show the turn below the Middle Neebish Rapids in the St. Marys River and the actual course of ships through it. With plenty of room on either side the ships make the turn more sharply than would be prudent in a narrow canal, and with entire safety. Observations taken to locate continuously ships passing this turn are plotted on the plates and show in many cases two turns of short radius instead of one of longer radius. The observations show that ships pass this turn at speeds up to 12 miles per hour. It will be noted that the width of the dredged channel is 600 feet above the turn and 300 feet below it. All the changes in direction in the Panama Canal, in the stretch above described, will be in a broader waterway, except at Obispo where the width will be practically the same. On the map prepared by the first Isthmian Canal Commission the canal line through Lake Bohio was indentical with the one

laid down by the French company, but it was not expected that ships would follow this line rigidly, and attention was called to the fact that Lake Bohio would be "a broad, deep body of water, affording room for anchorage as well as navigation." In the plan of canal advocated herein the lake is greatly extended, and lake navigation becomes a more important feature, so that it is deemed proper to present it more fully. The question is discussed with further detail in Appendix S.

For a distance of 4.7 miles through the deep portion of the Culebra cut the channel is to have a bottom width of 200 feet and to have nearly vertical sides below the water line, and then will become 300 feet wide for 1.88 miles to the Pedro Miguel locks, where the summit level will end. In the vicinity of the locks a low earth embankment without a spillway will be required on the west side.

The duplicate locks at Pedro Miguel will have one lift of 31 feet.

(E) LAKE SOSA.

Passing the locks, the channel will be 500 feet wide for 1.64 miles, then increasing to 1,000 feet or more for the further distance of 3.38 miles to the Sosa locks on the shore of Panama Bay. This broad navigation will be in an artificial lake created by three dams to be subsequently described. There are to be duplicate flights of locks on the west side of Sosa Hill near La Boca, with two lifts of about 31 feet each, from ordinary low tide to the level of Lake Sosa.

When the Board began its work, sufficient information for determining the feasibility of building dams to create a lake at the Pacific end of the canal was not available, and the Isthmian Canal Commission was requested to have additional surveys and borings made at dam and lock sites. As a result of investigations made in compliance with this request it was found to be entirely feasible to build three dams which would retain water to a height of 55 feet above mean tide, and create a lake having an area of about eight square miles, extending along the line of the canal to Pedro Miguel. It was also found that on the westerly side of Sosa Hill, near the La Boca pier, there is a suitable site for duplicate flights of two locks each.

The principal dam is the one at La Boca, which extends from the locks at Sosa Hill across the mouth of the Rio Grande to San Juan Hill. The other dams extend from Sosa Hill to Ancon Hill, and from Ancon Hill in the direction of Corozal to high land just across the Panama Railroad.

At the La Boca dam the greatest depth to rock shown by the borings is 64 feet below "spring low tide" and the material overlying the rock is impervious, consisting of mud and clay. At the other dams the borings showed rock but a short distance below the surface. The proposed cross sections of these dams are given on Plate XIV. They have very liberal dimensions, following in this respect the precedent established in the design of the Gatun dam.

The question having been raised as to the stability of the material at the site of the La Boca dam, the upstream side as well as the downstream side of the cross section of this dam was given a very wide base so as to insure the compression of the mud and clay rather than its displacement. During construction special provision will have to be made for shutting off the tidal flow in the Rio Grande, for which a sum has been allowed in the estimates.

In order to provide for the discharge of the Rio Grande and other rivers entering the lake during the construction of the earth dams, a diversion channel about 50 feet wide is to be cut through the slope of Sosa Hill, near the end of the Ancon-Sosa dam, and sluices or regulating works, similar to those proposed for the Gatun dam but of much less extent, are to be subsequently built in this channel.

The idea of building dams and forming lakes at or near the ends of the canal is not new, as it was suggested by Mr. Kleitz at the International Congress of Engineers, at Paris, in 1879. The Gatun dam was suggested in a discussion of interoceanic canal projects by Mr. Ashbel Welch, in March, 1880, before the American Society of Civil Engineers; both the Gatun and Pacific dams were again suggested by Mr. C. D. Ward in a paper read before that society on May 18, 1904, and both these sites are included in the projects recently presented to the Board by Mr. Lindon W. Bates. The official commissions, however, which have made reports on a lock canal, have favored carrying the tidal section of the canal up to Miraflores.

The advantages of the terminal lake are a reduction of about $8,000,000 in the cost of the canal and the greatly improved navigation, due to introducing 5.48 miles of channels not less than 500 and 1,000 feet wide and 45 feet deep.

In the project of the New Panama Canal Company, and also in that of the first Isthmian Canal Commission, tide water was to be reached at Miraflores, where the terminal lock was to be located.

The sea-level channel from Miraflores to La Boca is more objectionable than the one at the Atlantic end, on account of the great range of the tides at the former (20 feet at spring tides), which would produce tidal currents in the channel, and on account of the increased difficulty of maintaining the required depth by dredging. In excavating a channel to a depth of 40 feet below low tide from Miraflores to La Boca a considerable amount of rock would be encountered.

An objection may possibly be made, from a military point of view, to placing mechanical structures, such as locks, on the ocean shore exposed to the guns of hostile ships. Such an objection would apply also to the sea-level project with its terminal lock on the shore at the Ancon-Sosa saddle. The North Sea locks of the Amsterdam Canal are so placed. If the Panama Canal is to be neutralized, as the Suez Canal is, this objection has little force. A variant has been studied and estimated upon having the terminal lock at Miraflores, three and six-tenths miles inland, but it is not recommended because it costs much more and is less favorable for navigation.

(f) CHANNEL IN PANAMA BAY.

From the Sosa lock to the seven-fathom curve in Panama Bay, a distance of four miles, the channel is to be 300 feet wide at the bottom and 45 feet deep below mean tide. While this width and depth might be made greater with advantage to navigation, they are the dimensions adopted by the Board for the sea-level project with which the project here advocated is to be compared. Moreover, since it must be expected that considerable dredging will be required to maintain this channel, there is no doubt that it will be gradually enlarged by the dredges provided for maintenance.

Excepting near the locks the location of this channel is the same as that of the French company. It therefore renders available the excavation already made there by that company and, more recently, by the United States. With only a small amount of excavation access can be maintained for ships to the La Boca pier, built a few years ago at a cost of about $1,000,000. This pier will be of great service as a landing place during the construction of the canal, and very useful for a coaling station subsequently. The closing of the mouth of the Rio Grande by a dam, as previously described, will stop the existing tidal currents into and out of the estuary and entirely remove the most serious objection made by the Board to the French location.

(g) DIMENSIONS AND COST.

The waterway above described may be summarized with reference to channel widths as follows:

Width.	Length.	Per cent of route.
	Miles.	
1,000 feet	19.08	38.4
800 feet	3.86	7.8
500 feet	12.29	24.7
300 feet	7.21	14.5
200 feet	4.70	9.4
Locks and approaches	2.58	5.2
Total	49.72	100.0

It appears that only about one-seventh of the distance is in channels less than 300 feet wide, while for more than two-thirds of the distance the channels are 500 feet or more wide.

The estimated cost of the canal with summit level at elevation 85 as above outlined is, in round numbers, $140,000,000. If, for military or other reasons, the location of the terminal

locks on the Pacific at the shore line at Sosa should be deemed inadvisable and the location at Miraflores, three and six-tenths miles inland, be substituted, the cost of the canal would be increased about $8,000,000.

COMPARISON WITH THE BOARD'S LOCK-CANAL PROJECT.

The project for a canal with summit level at elevation 60 is fully described in the report of the Board. The principal differences between the two projects are:

The lower summit level in the project preferred by the Board.

In the Board's project the Gatun dam is to sustain a head of only 30 feet and the level above the dam is to be reached from the sea level by a single lift, duplicate locks being provided. Another dam and duplicate lock with equal lift will be located at Bohio, maintaining the summit level. There is to be a suitable wasteway in connection with each dam.

The low elevation of the summit level in the Board's project makes it necessary to regulate floods by building a dam on the upper Chagres, and the smaller size of the lake above the Bohio dam also requires the storage of additional water for lockage. The Board proposes to meet both of these requirements by a dam at Gamboa identical with that adopted for the sea-level canal.

In the Board's project the summit level is to be reached from the Pacific by two lifts instead of three, the locks being located at Pedro Miguel and Sosa, with the intermediate level at elevation 27.

The advantages of this project are:

1. The smaller head of water to be sustained by the dams at Gatun and Bohio than by the Gatun dam in the 85-foot project.

2. The smaller height of embankments required to maintain the intermediate level between Pedro Miguel and Sosa, the water surface being 28 feet lower.

3. The summit level would be lower and the locks reduced in number from six to four; there being no flights of two or more locks, but only a single lift at each locality, a transformation to a sea-level canal could be effected more readily.

4. The great lake to be formed by the Gamboa dam would afford control of the floods of the Chagres with less fluctuation of water in the canal.

5. The spillways would be smaller structures.

The disadvantages of the summit-level project preferred by the Board are:

1. The greater number of lock locations—at four points instead of three—which would require, until traffic becomes large, a little more expense for operation.

2. The greater number of dams and spillways on the Atlantic side, being three instead of one; one of the dams, that at Gamboa, far exceeding the Gatun dam for the 85-foot summit level in height and head of water sustained.

3. The great reduction of channel width, giving a canal less favorable for navigation.

4. The greater time required to build, estimated at two years.

5. The greater cost, estimated to be about $36,000,000.

The following table, classifying the channels of the two projects with regard to width and giving the proportion of each width, shows the great superiority for navigation of the canal with summit level at elevation 85.

Width of channel.	Proportion to entire length of route.	
	Summit elevation 60.	Summit elevation 85.
	Per cent.	*Per cent.*
1,000 feet	0.0	38.4
800 feet	0.0	7.8
500 feet	26.4	24.7
300 feet	52.1	14.5
200 feet	16.2	9.4
Locks and approaches	5.3	5.2
Total	100.0	100.0

The comparison of cost above given relates to the two projects as now planned. The provision for flood control and water supply for the project with summit level at elevation 60 is adequate for any traffic up to at least 100,000,000 tons annually, but if the project herein recommended with summit level at elevation 85 be adopted it will be necessary when the traffic reaches 40,000,000 or 50,000,000 tons annually to provide for storing water in the upper Chagres Valley. As Lake Gatun provides satisfactorily for flood control, storage will be required for lockage purposes only, and a much smaller dam than that proposed for the canal with summit level at elevation 60 will be ample until the tonnage reaches about 100,000,000 tons per year. Such a dam with the necessary wasteway would not cost more than $3,000,000, an expenditure which would not have to be made for many years, and would still leave a balance of cost of $33,000,000 in favor of the 85-foot level.

Most careful attention has been given to the question of transforming a lock canal into a sea-level canal, and the undersigned concur fully in the views expressed in the report of the Board that it is inadvisable to build a lock canal with a view to its transformation in the near future; and that, if not to be transformed soon, its construction should not be complicated with details which would increase first cost and detract from the efficiency of the lock canal. We believe, moreover, that a lock canal will have such advantages over a sea-level canal of the dimensions proposed by the Board that the transformation will not be called for in a very long time, if ever. The advantage offered by the canal with summit level at elevation 60 for transformation to sea level is therefore believed to be of little value.

Either of the two lock canals above compared would be convenient for shipping, although in a different degree, and would have a capacity for an immense traffic, larger than can be expected for a long time; but the better navigation afforded by the broad waterways of the canal with summit level at elevation 85, the simpler constructions, the shorter time required to build, and the great saving in cost are considerations too important to be neglected. The more costly canal would require more time to construct and would not serve navigation as well.

COMPARISON WITH THE BOARD'S SEA-LEVEL CANAL PROJECT.

The sea-level canal is fully described in the report of the Board. The most striking points of differences affecting navigation are with respect to number and dimensions of locks and dimensions of the waterway.

The Spooner Act provides that the canal "shall be of sufficient capacity and depth as shall afford convenient passage for vessels of the largest tonnage and greatest draft now in use, and such as may be reasonably anticipated." Since the passage of this act the Cunard Company has projected two ships for the North Atlantic route of very much larger dimensions than any built heretofore. The new ships are to be 800 feet long, 88 feet beam, and to have a draft of 36 feet. They are specially designed for fast service between England and New York. They are subsidized by the British Government, are to be at its service in time of war, and are not likely in any conceivable circumstances to traverse the Panama Canal. But the language of the act makes it necessary to plan the canal for these ships and for larger ones if they "may be reasonably anticipated." What are the ship dimensions which may be reasonably anticipated is a question about which great difference of opinion may exist.

The table shows the number of commercial and war vessels now in use, of medium size or larger, classified with respect to beam:

Beam of large ocean steamers.

Beam.	Commercial ships in use.	War ships in use or projected.	Total.
40 to 45 feet	2,101	201	2,302
45 to 50 feet	1,993	139	2,132
50 to 55 feet	692	110	802
55 to 60 feet	177	83	260
60 to 65 feet	53	44	97
65 to 70 feet	26	123	149
70 to 75 feet	6	85	91
75 to 80 feet	3	81	84
80 to 85 feet	.....	8	8
Total	5,051	874	5,925

This table shows most clearly how insignificant in number are the commercial ships exceeding 70 or even 60 feet beam. The broadest commercial ships in use are less than 76 feet beam, and if we exclude the projected Cunarders, which of all seagoing ships are the least likely to pass through the Panama Canal, a length of 700 feet and a beam of 76 feet may be taken as the dimensions of the greatest commercial ships now in use or building which are at all likely to pass through the canal.

The table also shows eight war ships projected of more than 80 feet beam. The beam of these is definitely known only for the new Japanese battle ships of the *Satsuma* class, which are to be 83 feet 6 inches.

The steady advance in ship dimensions since the introduction of steamships is well known, and while at almost any period there have been a few ships too large for the current traffic and existing harbor facilities it can not be doubted that as traffic increases and harbor facilities are improved ships of larger dimensions will come into profitable use. While a limit may be near at hand, as some well-informed experts believe, it seems clear that the limit has not been reached, although in the class of cargo steamers by which the greater part of the sea-borne commerce of the world is served there has been little or no general advance for several years. From such somewhat conflicting data a judgment must be formed as to what further increase of ship dimensions "may be reasonably anticipated." In forming such judgment it is believed that the period for which such reasonable provision is to be made should also be a reasonable one: for example, probably no one would expect to provide in any commercial or military construction for needs at the end of the present century.

The Board adopted for lock dimensions a width of 100 feet and usable length of 1,000 feet, which are sufficient for a ship of more than double the tonnage of the great ships recently placed on the North Pacific route, the *Dakota* and the *Minnesota* (which are so much larger than any other on the Pacific that they must be considered experimental), and are ample for a ship of about 40 per cent greater tonnage than the projected Cunarders, which are much larger than any other ship built or projected for any route. We believe this allowance for reasonable anticipation excessive, and that locks 95 feet wide with a usable length of 900 feet will fully meet the requirements of the act for both commercial and war ships, and recommend the adoption of these dimensions. They provide for ships nearly double the tonnage of the *Dakota* and *Minnesota*, or 25 per cent larger tonnage than the projected Cunarders. The width will permit the passage of a battle ship of 13 or 14 feet greater beam than any ship now in use or building for the United States Navy.

If the locks are larger than necessary, they will not only cost more, but will require a larger water supply and will not be quite so convenient to operate. The gates must be larger, the locks can not be filled or emptied so quickly, and therefore a little longer time will be required to pass ships; in other words, if the locks are larger than necessary, they will not serve commerce as well as smaller ones.

We do not believe it is wise to attempt to meet the possible requirements of a distant future, which might be estimated erroneously and would burden the commerce of the present and near future with unfavorable conditions, but that it would be more judicious to build the canal with reasonable but not excessive allowances for further developments. If the locks should prove, after many years, to be too small, larger ones can be built when needed, and in the meantime the structures of more moderate size will have rendered better service to commerce.

The second striking difference between the two projects affecting navigation is in respect to width of channel. Wherever, in recent times, natural waterways have been improved or artificial channels made for purposes of navigation the original work has been speedily followed by demands for deeper, wider, and straighter channels. All these particulars have been notably exemplified in the entrance channels to New York Harbor, where the new channel will have a width of 1,000 feet and a depth of 40 feet, and in the waters connecting the Great Lakes, where the channels, first made 150 to 250 feet wide and 10 to 12 feet deep, have been enlarged from time to time to widths ranging from 300 to 1,500 feet and to a depth of 21 feet. In accordance with an act of Congress estimates of cost of increasing the depth to 25 feet have been prepared and are about to be submitted. As a result of experience in these channels with a heavy traffic, much exceeding that in any other waterway in the world, curved channels are avoided entirely. Wherever practicable changes of direction are made in deep water; where this is impracticable the inner angle at the intersection of the two courses is cut off so as to make a large widening at this point, and ships make the turn in safety and usually without reducing speed. Ships are guided through the straight courses by center-line ranges and by frequent buoys, many of them gas-lighted, defining the foot of each side slope.

In the plan for the Panama Canal herein recommended, all of the route except the locks and a short length in the deepest part of the Culebra cut will consist of broad channels 300 to 1,000 feet or more in width, with changes of direction effected as above described. In the sea-level plan, on the other hand, such channels are found only in Limon Bay and from the tidal lock to the terminus in Panama Bay. About half the distance from Mindi to Miraflores would be in curves, and no widening of the channel in curves is provided for. Ships of the largest size could traverse the lock canal day or night without difficulty, but night navigation in the narrow curves of the sea-level canal would be hazardous except for smaller craft. In the following table the two plans are contrasted with respect to channel widths:

Bottom width of channel.	Lock canal with summit level at elevation 85.		Sea-level canal.	
	Length.	Per cent of route.	Length.	Per cent of route.
	Miles.		*Miles.*	
1,000 feet	19.08	38.4	0.00	0.0
800 feet	3.86	7.8	0.00	0.0
500 feet	12.29	24.7	4.87	9.9
350 feet	0.00	0.0	0.77	1.6
300 feet	7.21	14.5	3.05	6.2
200 feet	4.70	9.4	19.47	39.6
150 feet	0.00	0.0	20.39	41.5
Locks and approaches	2.58	5.2	0.59	1.2
Total	49.72	100.0	49.14	100.0

The lock canal will be less than 300 feet wide for only one-seventh of its length and for more than two-thirds of its length will be 500 feet or more wide; it will be nowhere less than 200 feet wide. The sea-level canal for nearly half its length would be only 150 feet wide, and for nearly five-sixths of its length would not exceed 200 feet. Moreover, in the portion 200 feet in width there are stretches where the lower part of the canal is in rock which does not reach the surface of the water, a condition particularly unfavorable to safe navigation.

The lock canal is not only greatly superior to the sea-level canal in regard to width, but is also decidedly superior in regard to depth. The sea-level canal is planned to be 40 feet deep below the level of mean tide except in Limon Bay, where it would be 41 feet, and in Panama Bay, where it would be 45 feet below mean tide.

At low tide the depth of water in the canal for some distance inland from Limon Bay would be a little less than 40 feet. The plans for the sea-level canal contemplate the direct admission of the water of silt-bearing rivers of moderate size into the canal, and, in some instances, into the portions of the canal having a rock bottom. Under such conditions it will be difficult and expensive to maintain the full depth of 40 feet by dredging. In the lock canal, as planned, the sea-level section on the Atlantic side will have a depth of not less than 40 feet of water throughout at any stage of the tide. In the summit level the depth will be 42 feet or more at extreme low water in the driest season, and 45 feet or more under usual conditions. From Pedro Miguel to Sosa the depth will be 45 feet or more. The decided advantage to large ships of these increased depths will be recognized by all who are familiar with the difficulty of steering when there is but little water under the keel.

RELATIVE TIME FOR COMPLETION OF SEA-LEVEL AND 85-FOOT PROJECTS.

The Board estimates that the sea-level canal can be built, with favoring circumstances, in twelve or thirteen years, this being the estimated time required to excavate the central mass usually called the Culebra cut, including all the excavation between Obispo and Pedro Miguel. This section is 8.08 miles long, and for the sea-level canal requires 110,000,000 cubic yards of excavation, the heaviest mile requiring 22,000,000 cubic yards and the heaviest 3,136 feet (which is the length of the Gatun flight of three locks for the 85-foot level canal), 14,000,000 cubic yards.

This estimate of time is based on an estimated output of 800 cubic yards per day of ten hours for each steam shovel employed, the number of steam shovels to be increased to 100 as rapidly as they can be installed. Toward the end of the work the space would be restricted and the number of shovels would have to be reduced. It is recognized by the Board and by all others who have given attention to the subject that the real problem of excavation is to dispose of the excavated materials and to keep empty cars at the shovels for filling. Up to this time great difficulty has been found in the wet season in maintaining tracks and unloading cars, and the cost of experimental work done by the Isthmian Canal Commission was quickly and greatly increased when the rainy season came on.

The estimated average output above mentioned could easily be reached and even exceeded in a favorable climate, and in material suitable for steam-shovel work; but at Panama only three or four months each year can be called dry, and in the remaining months two or three times as much rainfall is concentrated as occurs in the entire year in the central and eastern parts of the United States. As to the material, the greater part of it will require blasting while much of it is hard rock. The average output estimated for shovels at the canal is nearly double that realized in mixed materials in several large operations in the United States.

We believe the time required to excavate the Culebra cut for the sea-level canal will be much greater than estimated by the Board and not less than fifteen years. This conclusion has been reached by considering the Culebra cut as a whole, studying the possible arrangements of tracks and distribution of plant, and also with special reference to the heaviest portion, about 4,300 feet in length. The lock canal with summit level at elevation 60 will require 72,800,000 cubic yards of excavation from the central mass, and assuming the time will be proportional to the amount to be excavated from this mass and that the sea-level canal would require fifteen years, the time required to complete the lock canal with summit level at elevation 60 would be ten years. On the same basis the time required for the lock canal with summit level at elevation 85, which requires the excavation of 53,800,000 cubic yards from the central mass, would be about seven and one-half years, a conclusion which is verified by a study of conditions in the heaviest portion; but before accepting this period as the time required to build the canal consideration must be given to the question of time required to build the locks.

For the 85-foot level the greatest amount of lock excavation and the greatest amount of lock masonry will be required at Gatun. The amount of excavation for this lock, embracing a distance of 3,136 linear feet, measured along the canal axis, will be 3,660,000 cubic yards, and the average width of the excavation will not differ greatly from the average width of the Culebra cut in the heaviest section. The excavation of the corresponding length of the heaviest section of the Culebra cut in fifteen years will require the removal of 933,000 cubic yards per year. If this rate can be maintained at the lock site at Gatun the excavation would require four years. It does not appear that the materials at Gatun are any less favorable to excavate than at Culebra, while the distance to a dumping ground would be less, and the excavating plant could be arranged for more effective use, and therefore a somewhat better rate should be reached at Gatun; but if no reduction be made on account of these better conditions the estimated time will be on a more conservative basis than the estimate of the time for the sea-level canal.

The amount of concrete masonry required for the Gatun locks will be about 1,300,000 cubic yards. This would be the greatest mass of masonry built in modern times. Like the excavation of the Culebra cut it will require special organization and the best plant. Plant and materials should be accumulated in advance while the excavation is being made. With such preparation a very rapid construction is practicable. In recent work in the United States an average of about 400 cubic yards per day was maintained for a considerable period with a single mixing plant, and a maximum was reached of more than 800 cubic yards in one day. At the Gatun locks, with their three main walls aggregating more than 9,000 linear feet, 20 mixing plants or even more could be set up and operated to advantage, and at the average rate of 400 cubic yards per plant per day the daily rate would be 8,000 cubic yards. But assuming a very large reduction from this—that only ten of these plants were operated simultaneously, with an average output of only 250 cubic yards per day for each—the daily rate would be 2,500 cubic yards, which is certainly easily attainable and may be much exceeded. At this rate the entire amount of concrete would be placed in 520 working days, or two and a quarter years. The materials for this daily output of concrete would amount to about 4,000 tons, or, say, 125 carloads. This is about one-fifteenth of the weight of the excavated materials to be moved daily from the Culebra cut, and it does not appear to offer any special difficulty.

The largest item of work remaining is the erection of the gates, of which 14 pairs will be required for the duplicate flight. At the Poe lock of the St. Marys Falls Canal five pairs of gates were erected with a small force and a single plant in sixteen and a half months, of which about six months were winter, and in that extremely cold climate little progress could then be made. Deducting half of this period, the period of effective work was not more than thirteen and a half months, giving less than three months as the time required for the erection of one pair of gates. Not less than five plants should be provided for the 14 pairs of gates at Gatun, and if we assume five months instead of three months as the period required for one pair on account of the greater size of the gates, the total time for all the gates at this lock would be fifteen months, or one and a quarter years. As the plants are not expensive, they might be further increased in number, and if seven were employed the time required would be only ten months, or, say, one year. As this work could be done under roof, little time need be lost on account of rain.

The periods above mentioned aggregate seven and one-fourth to seven and one-half years, which is less than required for the Culebra cut; but this aggregate results from assuming that excavation would be entirely completed before making concrete was commenced, and that the concrete would be entirely completed before the erection of the gates was taken up. These operations would, in fact, overlap and, to a considerable extent, be carried on together, effecting considerable reduction in total time.

The locks at Pedro Miguel and Sosa are of less magnitude than the Gatun locks and would require less time, and no other single work except the Culebra cut would require nearly as much. Nevertheless, where so many works of magnitude are to be built there is likely to be delay at some point, and the period of seven and one-half years for the construction of locks might be exceeded somewhat.

The period of seven and one-half years above given as required for the Culebra cut is based upon the same average number of steam shovels as required to complete the Culebra cut for the sea-level canal in fifteen years. Since the installation of the full number of steam shovels, tracks, etc., would require about the same time for either canal, and when the width of the cut becomes smaller toward the bottom there will not be room to operate so many, the average number in use for the lock canal will be less, and we therefore increase the estimated time required for the Culebra cut for the lock canal one year, making eight and one-half years. Until recently no one, so far as we are aware, has estimated a longer period than eight years for the construction of the locks in any project or, in fact, so long a period.

The French company allowed ten years for the various works at Bohio, including the dam, spillways, and locks, but this resulted from a plan of successively executing parts of these works; and the construction of the lock, including masonry, gates, and other appurtenances, was estimated to require only six years, of which two years were allowed for excavation. The first Isthmian Canal Commission based its estimate of time required for completion of the canal wholly upon the excavation of the Culebra cut, estimated to require eight years after the period of preparation.

Making due allowance, as before indicated, for possible delays in the concurrent execution of several works, and taking a total of nine years for the entire work, we arrive at a period which we believe to be far more conservative than the period of fifteen years for a sea-level canal. A saving of at least six years will result from the adoption of the plan herein recommended instead of a sea-level plan.

RELATIVE TIME OF TRANSIT.

In the sea-level canal it will be necessary for one of two ships of medium or large size about to meet to make fast to mooring piles or posts while the other passes at reduced speed. In the Suez Canal this is done in all cases, and at regular mooring places where facilities are supplied. At these mooring places, which are usually about four miles apart, the canal is widened for a distance of about 2,400 feet from the ordinary bottom width of about 108 feet to about 150 feet. The latter is the bottom width proposed for the greater part of the sea-level canal, but as the Panama Canal is intended to provide for larger ships than any now passing through the Suez Canal, it is assumed that passing places will be made in the 150-foot channels of the former, although the estimates of cost do not provide for them. In the Suez Canal no meetings are allowed where the canal passes through rock. It is here assumed that passing places will be made at Panama in all materials, unless the bottom width is as much as 200 feet with sides vertical and continuous for a considerable distance, as in the Culebra cut, or unless, if the sides are flat slopes, the bottom width is 300 feet or more. In the Culebra cut, where the sides are vertical, it can be arranged to make a ship fast anywhere. In channels 300 feet wide ships can pass each other at reduced speed without stopping. In widths of 500 feet or more it will not be necessary for either to reduce speed.

The broad channels afforded by the lock canal with summit level at elevation 85 will enable ships to pass through them at much greater speeds and with much greater safety than in the narrow channels of the sea-level canal, and as there will be only a small proportion of channel less than 300 feet wide in the lock canal, very little loss of time will occur at meeting points; but in the sea-level canal, with its narrow channel all the way across the Isthmus, the time lost at meeting points will be considerable, even with moderate traffic, and will increase with great rapidity as traffic increases. With ships of such size as those of the principal lines between western Europe and the Orient, the time lost by meetings and by the lower speeds through the narrow waterway of the sea-level canal would be greater than the time required for lockage through the several locks of the lock canal. With ships approaching in dimensions those contemplated by the act of Congress authorizing the building of an isthmian canal, the transit across the Isthmus, even with a small traffic, would require more time in the proposed sea-level canal than in the lock canal herein recommended, and with a heavy traffic the loss of time would be an important feature.

In order to test the relative time required for passage through these respective canals, a calculation has been made of the time required in each, following the methods described in detail

in the report of the Isthmian Canal Commission of 1899–1901. (See Appendix G of that report.) Since the time of transit will vary with the dimensions of the ships and the density of traffic, two type ships were selected, one called type C, 540 feet in length, 60 feet beam, and 32 feet draft, the other called type E, 700 feet in length, 75 feet beam, and 37 feet draft. The former is not quite as long or broad as the larger ships of the Union Castle Line, which run between England and the Far East via the Cape of Good Hope; the latter is a little larger than the largest ships now on the Pacific, but not so large by 30 to 40 per cent as the largest ships which could pass conveniently through a canal of the channel and lock dimensions proposed for the Panama Canal with summit level at elevation 85. The results of this calculation are summarized in the following table:

Type of ship.	Distance between passing places.	Type of canal.	Time required for transit across the Isthmus.				
			10 ships per day.	15 ships per day.	20 ships per day.	25 ships per day.	30 ships per day.
	Miles.		*Hours.*	*Hours.*	*Hours.*	*Hours.*	*Hours.*
Type C, 540 feet by 60 feet by 32 feet	5.0	Sea level	8.9	9.6	10.5	11.5	12.9
	2.5	do	8.6	9.0	9.7	10.3	11.1
		Lock	9.5	9.6	9.7	9.8	10.0
Type E, 700 feet by 75 feet by 37 feet	5.0	Sea level	11.6	12.8	14.3	16.2	18.9
	2.5	do	11.1	11.6	12.6	13.6	14.7
		Lock	10.5	10.7	10.8	10.9	11.1

The saving of time by reducing the distance between passing places is apparent, but even for ships of the smaller type the lock canal will furnish quicker transit when the traffic becomes great, while for the larger ships the lock canal will afford quicker transit from the start. This would be still more marked for ships of the greater dimensions contemplated in the act of Congress. By increasing the width of the sea-level canal the time of transit would be reduced. If it were made 300 feet wide, except for 4.7 miles in the Culebra cut, the time would be less than in the lock canal with summit level at elevation 85 on account of the time lost at locks in the latter, but the cost of such a canal would be about $50,000,000 greater than that of the sea-level canal adopted by the Board.

In the narrow channels of the sea-level canal, with its large proportion of curves, night navigation will be more hazardous than by day, and ships will probably move at lower speed than assumed for the calculation of time of transit. Unless ships arrive very early in the day, they will not be able to pass through the canal by daylight on the day of arrival, but will have to submit to the delays of night navigation or tie up until the next day. While this may not appear to be an important matter, the loss from an average delay of twelve hours would amount to a large sum in a year. Taking, for example, a tonnage of 20,000,000, the annual loss on the basis of earnings of one-half mill per ton mile would not be less than $1,500,000, which, capitalized at three per cent, shows that an expenditure of $50,000,000 would be justified to avoid such a delay. It must be evident that even a small delay to the traffic is of much importance. By the adoption of the summit-level canal, instead of a sea-level canal, the time of transit is shortened, not only without additional cost but with a large saving.

CAPACITY FOR TRAFFIC OF THE TWO PROJECTS.

The best example of a ship canal with locks and modern equipment and a large traffic is the St. Marys Falls Canal, and it is therefore the best precedent in discussing the traffic capacity of a lock canal at Panama. The claim is made in the report of the Board that it is not a maritime canal, and that for this reason experience there is not a safe guide for the consideration of a canal for seagoing ships. This demands most careful attention. The other great ship canals with locks are the Manchester, the Amsterdam, and the Kaiser Wilhelm or Kiel, all of which connect with the sea at one or both ends.

The publication of the Department of Commerce and Labor entitled "Great Canals of the World" gives the traffic through the Manchester Canal for the years 1894 to 1900, inclusive, and through the Kaiser Wilhelm Canal for the years 1895 to 1904, inclusive, brought down to 1905 by later information from that Department. No data are given for the Amsterdam Canal nor are any readily obtainable for this report.

The traffic through the Manchester Canal in the last year reported, 1900, was 1,492,320 tons net register. The number of vessels was 5,362, giving an average tonnage of only 278. These figures include, however, a large proportion of small vessels not seagoing. Taking only the vessels going to Manchester, the number was 2,900, the registered tonnage 1,230,784, and the average tonnage per vessel 424. Exact figures as to the present tonnage are not available, but it is probably about one-third more. The largest ships traversing the canal up to this time are the twin-screw steamers of the *Somerset* class, 460 feet long between perpendiculars and 58.2 feet beam; single-screw steamers of the *Silverlip* class, 470 feet between perpendiculars and 55.2 feet beam, and the Manchester liners, single-screw cargo steamers, of which the larger are approximately 400 feet between perpendiculars and 50 feet beam.

The traffic through the Kaiser Wilhelm Canal during the year ending March 31, 1905, was 5,720,477 tons in 32,623 vessels having an average tonnage of 162. A large proportion of the larger ships were German war vessels, 648 of these having passed through the canal in that year.

There are two canals at the St. Marys Falls, the canal on the American side having two independent locks, one called the Weitzel lock, 515 feet long, 60 feet wide at the gates (80 feet in chamber), and 17 feet over the sills; the other, called the Poe lock, 800 feet long, 100 feet wide, and 22 feet over the sills. The canal on the Canadian side has a lock 900 feet long, 60 feet wide, with 22 feet over the sills. In 1905, 19 per cent of the tonnage passed through the Weitzel lock, 66 per cent through the Poe lock, and 15 per cent through the Canadian lock. The sailing route is a little shorter via the American canal, and the canal has nearly vertical sides; in the Canadian canal the sides have a slope of four on one, and floating fenders are in use to keep vessels from injury, but are not satisfactory; for these and other reasons the greater part of the traffic passes through the American canal. The depth of water on the sills of the Weitzel lock is not sufficient for the larger vessels when loaded, and it is used mostly by vessels of smaller size. The locks therefore effect a classification of vessels, the largest always passing the Poe or the Canadian lock when loaded, and usually when light. None of the locks is worked to its full capacity.

In 1905 the total net registered tonnage passing through the two canals was 36,617,699 tons, the number of vessel passages (excluding scows, etc., not registered) being 20,460, and the average tonnage 1,790. The net registered tonnage through the Poe lock was 24,176,472, the number of vessels 9,374, and the average tonnage 2,579.

These comparisons appear more clearly in the following table where the preceding figures are collected. The tonnage through the St. Marys Falls Canal is net register, and it is presumed the tonnage for the other canals is of the same measurement.

Canal.	Year.	Number of vessel passages.	Tonnage.	Average tonnage of vessels.	Remarks.
Manchester	1900	5,362	1,492,320	278	All vessels.
Manchester	1900	2,900	1,230,784	424	Manchester trade only.
Kaiser Wilhelm	1905	32,623	5,270,477	162	Year ending March 31.
St. Marys Falls	1905	20,346	36,617,699	1,790	All locks.
St. Marys Falls	1905	9,374	24,176,472	2,597	Poe lock only.

After an inspection of this table a claim that experience in regard to the navigation of lock canals is to be looked for at the Manchester or the Kaiser Wilhelm canals rather than the St. Marys Falls Canal would appear preposterous. It would require only 480 vessels of the average size passing the Poe lock during the present year to equal the tonnage of the 2,900 vessels

passing through the Manchester Canal in 1900, and only 2,044 to equal the tonnage of the 32,623 vessels passing the Kaiser Wilhelm Canal during the last year.

If, however, the dimensions of the largest class of ships passing the respective canals be compared, the result is more favorable to the foreign canals. The largest vessels passing the Manchester Canal are, as stated before, 460 feet by 58.2 feet, and their draft of 25 feet is practically the depth of the canal. Similar information as to the Kaiser Wilhelm Canal is not at hand, but it is probable that the largest vessels there are the war ships of the German navy. The largest vessels passing the St. Marys Falls Canal are 549 feet between perpendiculars, 56 feet beam and 20 feet draft, and are comparable with the largest vessels reaching Manchester. In model of hull, power of engines, and speed they are similar to ocean-going cargo steamers, although not as strong structurally. The principal differences are in the draft, which is four to five feet less, the location of engines, arrangement of deck, and other minor details which do not affect their adaptability for canal navigation.

Having in consideration all the foregoing facts, we believe not only that the experience gained at the St. Marys Falls Canal is applicable to the navigation of the Panama Canal, but that it is of vastly more value than any or all experience in the foreign lock canals. The amount and character of traffic through the foreign canals does not suffice to prove the capacity and suitability of a lock canal for a great traffic, because none of them carries such a traffic, but the St. Marys Falls Canal supplies the deficiency and makes the proof complete and, indeed, overwhelming.

Nevertheless, it is contended by the Board that the St. Marys Falls Canal is used by ships that frequently pass it, and that the pilots and crews are familiar with all the operations of passing locks, while the Panama Canal would be traversed by ships with crews ignorant of these matters, and therefore the record of safety and capacity so completely established in the American canal could not be paralleled at Panama, but, on the other hand, the most imminent risk and vexatious delays would be incurred at all times. We can not help believing that due consideration concerning the things required to be done to pass a canal lock would dispel these apprehensions.

The movement of a ship is controlled in both cases by signals transmitted from the pilot house to the engine room; the engineer must check, stop, start, etc., when ordered; he is accustomed to doing so quickly, whether at sea, in a canal, or in a harbor, whether approaching a landing or a lock. The engines are practically of the same type. As a ship nears a lock lines will be put out, carried by the lock tenders and placed on snubbing posts as required, the ship's sailors having only to haul in, to make fast, to slack off or pay out, which they ought to do more skillfully than the less trained deck hands on lake ships. All of these operations will be required at the passing places in a sea-level canal and under more difficult conditions than at locks. Furthermore, on each ship while in the canal there will be a pilot whose entire time will be given to the handling of ships in the canal and who will be not less skillful than the lake pilot who is in a lock canal for only an hour two or three times a month.

The estimate of the Board as to the possible number of lockages per day "perhaps not exceeding ten per lock or twenty per pair" is at variance with American experience. As many as 36 lockages have been made at the Poe lock in one day, passing 93 vessels. The estimate of lockage capacity given in Appendix L is based on actual performance, which the estimate of the Board ignores.

The want of data concerning the Amsterdam Canal is regretted, for there is some reason to believe that it might make a more favorable showing as a commercial ship canal than either the Manchester or the Kaiser Wilhelm canals, but the general results of the preceding discussion would not be affected.

The experience at the St. Marys Falls Canal is particularly important in establishing the capacity of a lock canal for traffic, because its nearest parallel in point of magnitude of traffic is a canal with no lock, viz, the Suez Canal. The tonnage through the Suez Canal in 1904 was 13,401,835 tons, Danube measurement, or about 11,500,000 tons net register, since the Danube measurement is 16 to 20 per cent greater. This is less than one-third the tonnage through the St. Marys Falls Canal in 1905 and less than half the tonnage through the Poe lock alone. Taking

into account the short navigation season at the St. Marys Falls Canal, the tonnage per month during the navigation period of 1905 was three times as much through the Poe lock alone as at Suez.

The Suez Canal is traversed almost exclusively by seagoing ships making long voyages, and therefore of large size. The average measurement of the 4,237 vessels passing in 1904, about 2,700 tons net register, is more than six times that of the vessels passing through the Manchester Canal to its terminus in 1900, and about sixteen times that of the vessels passing through the Kaiser Wilhelm Canal during the last year. It is about 50 per cent greater than the average tonnage of the vessels passing the St. Marys Falls Canal during 1905, but only 10.5 per cent greater than the average of those passing the Poe lock. The portion of the tonnage through the Poe lock which is carried in vessels equal to or exceeding the average measurement of the ships passing the Suez Canal is largely in excess of the total tonnage at Suez.

Finally, the aggregate tonnage passing all the four foreign canals above mentioned is much less than that passing the St. Marys Falls Canal, and is even less than that passing one only of the three locks in use there. The average tonnage of the vessels in these foreign canals is but little more than one-fourth the average of those passing the St. Marys Falls Canal and but little more than one-sixth the average of those passing the Poe lock. With these facts in mind there can be no need of further argument that this canal, although neither end touches salt water, furnishes abundant proof of the suitability of a canal with locks to serve a great commerce carried in ships of any size.

The duplicate locks of the Panama Canal will afford convenient passage for an annual net registered tonnage of 80,000,000, as shown in more detail in Appendix L.

SAFETY OF LOCKS AND OTHER STRUCTURES.

The most plausible arguments advanced by advocates of a sea-level canal to justify its greater cost and the greater time required to build it are the alleged danger of carrying away the lock gates at either end of the summit level if a ship moving at speed should strike them, and the possible damage to structures through malice or in time of war.

An accident to gates, if it occurs, is most likely to result from a mistake in the engine room, the engineer sending the vessel ahead when the pilot signals to back, and then the pilot, noticing that the ship's speed is not being reduced and not realizing that the previous signal is not being carried out, signals for full power or perhaps signals so rapidly that he can not be understood. One or the other of these successions of events has usually taken place when a ship has run into lock gates. The carrying away of a lock gate occurs but rarely, but it has occurred three times in the Manchester Canal. It has never occurred in the St. Marys Falls Canal.

In the Manchester Canal the gates at the lower end of the lock were struck, the upper gates being open, the ship moving downstream, but in all cases the operating force was able to get the gates at the head of the lock closed, or so nearly closed that they came together and held back the water in the canal. If such an event should occur at Panama, where the locks are in duplicate, traffic through the injured lock would be suspended until repairs could be made. With duplicate gates in stock the repairs could probably be made and traffic resumed through the injured lock without a prolonged delay. In the meantime, traffic would be continued through the duplicate lock, and although, if the traffic were great, it would be subject to some inconvenience, yet it would be maintained.

If, however, the gates supporting the summit level should be carried away and the current flow unobstructed through the locks with no means in readiness to stop it, such, for example, as a movable dam, the result would be very serious indeed. It would require many days to lower the level of Lake Gatun sufficiently to render the task of closing the opening through the lock easy, and in the meantime the channel and the works below the lock might be seriously damaged and navigation suspended for weeks or months. The chances for such a disaster are so small that if the Panama Canal were intended for commercial purposes only, the great additional expenditure required to make it a sea-level canal would have few advocates, but the possible need

of the canal for the passage of ships in time of war strengthens the argument for a sea-level canal and makes it necessary to consider with care the chances of such an event in ordinary canal operation, the facilities for handling and controlling the movement of ships which may be used, the precautions for safety which may be introduced in the operation of the locks, and the constructions which may be supplied to close off the current should it be set up.

We believe that in no ship canal in the world has such a disaster occurred as that imagined for the Panama Canal. If the accidents at the Manchester Canal show that gates may be struck and destroyed, they also show that disaster may be averted even without special safeguards. Of all the possible movements of a ship at canal locks the one that involves the most danger of opening a summit level is when a ship bound down in that level approaches a lock, but by proper safeguards this can be made very small. If a gate is struck by a ship upward bound the water pressure on the opposite side of the gate helps to resist the blow. By the use of two pairs of gates at each end of the summit lock all danger of opening the summit level by a blow on the downstream side of the lower gates is eliminated, as will be shown a little farther on.

The canal construction should provide long approach walls at each end of every lock or flight of locks so that lines can be put out quickly and handled readily and the ship held under perfect control. For this important purpose a long solid pier with suitable snubbing posts is vastly superior to mooring piles and floats, such as are used in some foreign canals. No canal in Europe is adequately provided in this respect, and the apprehensions of some members of the Board in regard to the hazards of navigation through lock canals may be due to the fact that their experience has been entirely with canals having this radical defect. With suitable approach piers and with rules duly enforced requiring ships to put out lines on arriving at the pier and to reduce speed to two miles per hour when moving along it, or to stop altogether several hundred feet from the lock, a great degree of security can be obtained. Such approach piers are provided in the lock plan herein recommended.

This plan also provides two pairs of gates at the head and two at the foot of each summit lock, so that a ship will always find two pairs of gates shut against it.

If the summit level is terminated by a single lock and the lower gate is struck by a ship upward bound, the gates at the upper end of the lock being open, the lower pair of gates at the foot of the lock having water pressure back of them will absorb the blow, and even if they are wrecked the second pair of gates, some 80 feet distant, will not be reached. The resistance offered by the first gates will almost surely stop the ship, and the rush of the mass of water, 80 feet in length between the two gates, will insure stoppage before it can reach the second pair. If the lower end of the lock is open and the upward-bound ship strikes the first pair of gates at the upper end of the lock its motion will be stopped by these gates, the miter wall, and the water, and the second pair of gates will be left intact. We believe, therefore, that, by the use of duplicate or safety gates at each end of the summit lock, all danger of opening the summit level by an upward-bound ship will be eliminated.

If a downward-bound ship is approaching the gates from the summit level it will find at least two pairs of gates closed against it, of which the first will be sustaining no water pressure to weaken the strength available to stop the ship. While this case does not afford the absolute security shown in the case of ships moving upstream, the possibility that the ship will so completely wreck the first pair of gates as to continue its course to the second and seriously harm it is extremely small. A large lock gate is a massive structure, not easily wrecked. The gates of the Poe lock have been struck three times and injured more or less, but they continued to support the summit level.

The provision of duplicate gates at each end of a lock herein adopted is an unusual precaution. It has been recently adopted in part at the St. Marys Falls Canal, where duplicate gates are now operated regularly at the lower end of the Poe lock, but the upper end is not similarly protected. In the additional lock now projected at that canal safety gates are to be provided at each end. The approach piers, the extent of which greatly affect the safety of a lock, are excellent at the St. Marys Falls Canal and far better than at any other ship canal, and doubtless have contributed to the remarkable record of immunity from serious accidents.

This canal has now been in operation a little more than fifty years and a traffic aggregating about 360,000,000 tons net register has passed through it, with no accidents seriously obstructing navigation. It is the best example existing not only of the capacity of a lock canal for a great traffic but of the safety with which this traffic can be handled with suitable equipment.

In view of these facts relating to the operation of canals not as well provided with safety appliances as proposed for the Panama Canal it appears fanciful to enlarge on the dangers of a lock system; but even the small risk which a lively imagination might still assign to a lock canal can be substantially diminished, since it is not impracticable to stop the flow from a summit level, if once set up. Several devices have been built to control the flow of water from the summit level in case lock gates should be carried away. More than forty years ago a pair of gates provided with powerful brakes to check their movement while closing in a current was placed about 3,000 feet above the locks in the St. Marys Falls Canal. The gates were removed about fifteen years later when the canal was deepened, before any occasion had arisen to use them for the purpose intended. When the channel was deepened a construction was adopted consisting of a series of wickets, each so small that its movement could be controlled by machinery of moderate power. The wickets were carried by a swing bridge, and when not in use the bridge was open and the wickets were then on land, where they could be inspected and repaired. The canal force was trained regularly in the handling of this device so that they might work efficiently in case of actual need. For such experimental practice the same procedure was followed as in a real emergency, viz, the bridge was swung across the canal and the wickets lowered one by one, their lower ends resting against a sill at the bottom of the canal, the upper ends supported by the bridge. After about eighteen years the canal was again deepened and the device removed before any accident requiring its use had occurred. A modified form of the device was built at the Canadian canal at the St. Marys Falls about ten years ago, but is yet untried, and another is about to be supplied for the American canal. The problem of working out a satisfactory device for this purpose in the deeper channel of the Panama Canal is a difficult one, but no doubt is entertained that a solution can be made. For such appliances the sum of $2,000,000 is included in the estimate of cost.

A lock may suffer other injuries, and will require repairs, during which navigation through it may be interrupted. For this reason, principally, duplicate locks are provided, so that if one is under repair navigation may continue uninterrupted through the other. It is seldom that a lock is put out of use, and the simultaneous disabling of two would be very unlikely. A brief summary of fifty years' experience at the St. Marys Falls Canal is given in Appendix S.

The canal structures most exposed to injury through malice or in time of war are the locks and wasteways. In the sea-level canal there would be three such points—the tide lock at Ancon, the sluices at the Gamboa dam, and those between Ancon and Pedro Miguel, the last named being of small importance. There will be five in the lock canal herein advocated—the locks at Gatun, Pedro Miguel, and Sosa, the sluices at the Gatun dam, and the sluices or wasteway in the Ancon-Sosa saddle. The latter is so small and may be so securely founded on rock but little below the level of the canal that no possible injury to the structure would interfere seriously with navigation. The Ancon lock of the sea-level canal and the Sosa locks of the summit-level canal are equally exposed to attack by a naval force.

While it is conceivable that a malicious person or a crank might carry enough concealed high explosive to injure a lock gate or a sluice, experience of many years of perfect immunity in all the ship canals shows that this is not a real danger. The only disaster to be seriously considered is one that might be inflicted by a hostile force in time of war. If the enemy had control of the coast, or occupied territory inland in the vicinity of the canal, enough high explosive could be carried through the tropical jungle by a small force to destroy any of the lock gates or sluiceways, or to sink a ship. In order to open the summit level effectively and cause a suspension of navigation for a long time it would not only be necessary to destroy two pairs of gates, but also the device already referred to for closing the channel in a current. So large a force and so much time would be required to do all this that it could be effected only by a force superior to the

strong guard which in time of war would certainly be stationed at every important canal structure.

It has been suggested that a vessel carrying a large quantity of concealed dynamite could be exploded in a lock and wreck not only the gates but the masonry. While the execution of such a plan is extremely improbable, there are three places where it might be attempted in a summit-level canal and one in a sea-level canal. In either case the duplicate system of locks would reduce the hazard very much.

But it must be remembered that it is easily possible to block a sea-level canal by the sinking of a vessel in its channel, either by design or by accident, such an accident, for instance, as that which caused the steamship *Chatham* to absolutely block the Suez Canal and suspend all traffic through it for a period of nine days, from September 27 to October 6, 1905.

This accident occurred in time of peace in a sea-level canal, thirty-six years after its completion. During the period of fifty years since it was built there has been no such protracted interruption to traffic in the lock canal connecting Lake Superior with the lower lakes, and the delays in the channels away from the locks have constituted the most serious interruption to traffic on that waterway.

It is therefore evident that the structures are not the only vulnerable points in a waterway across the Isthmus. The locks and wasteways could be much more readily guarded than the whole length of the canal. At almost any point on the sea-level canal the attempt might be made to explode dynamite under a passing ship, which, if successful, would close the narrow channel effectively. There are many places on the route where this could be done more safely to the hostile party than at the locks. To this danger ships would be much more liable in the narrow channel of the sea-level canal than in the broad waterway of which the lock canal mainly consists.

We believe that unless the canal were declared neutral by general agreement among civilized nations the maintenance of navigation through it in time of war and with an active hostile force in the vicinity would be difficult; but the danger under this condition does not differ greatly whether the canal be a sea-level or a lock canal.

Possible injury by earthquakes to a canal across the Isthmus has received much discussion and much has been made of it by opponents of any canal. It was treated fully and fairly by the first Isthmian Canal Commission, and the following opinion expressed, which is entirely applicable to the lock canal herein advocated, and in which we concur:

> The works of the canal will nearly all of them be underground. Even the dams are low compared with the general surface of the country, and, with their broad and massive foundations, may be said to form part of the ground itself, as they are intended to do. The locks will all be founded on rock. It does not seem probable that works of this kind are in any serious danger of destruction by earthquakes in a country where lofty churches of masonry have escaped with a few minor injuries.

A large number of engineers on both continents, including four members of this Board, have in previous years concurred in recommending lock canals as feasible and adequate waterways across the Isthmus. While the ships to be provided for in the present projects are larger, the increase is not so radical as to make the forms of construction which were feasible and adequate for the ships then contemplated "altogether beyond the limit of prudent design for safe operation" and without "reasonable assurance of safe and uninterrupted navigation" for the ships now under consideration, as asserted by the Board.

RELATIVE SAFETY OF SHIPS IN THE TWO TYPES OF CANAL.

The comparison between the two projects must relate principally to conditions at the locks in the summit-level canal and in the narrow channel of which the sea-level canal mainly consists. While there will be a short section of channel only 200 feet wide in the summit-level canal it will be so short that it will not affect in an important degree any conclusions that may be drawn if it be neglected; and similarly, while there is to be one lock in the sea-level canal there are six in the summit-level project, and the tidal lock of the former may be neglected in this connection.

A lock is a short section of canal, with vertical sides, in which ships are moved at a low speed and under perfect control. A ship is in much less danger of injury in a canal lock than

when landing at a pier in the most favorable conditions with no wind or current. Experience at the St. Marys Falls Canal, where no vessel has been seriously injured in a lock during fifty years of continuous use, should be conclusive on this point. Danger to ships in a canal is not at the locks, where they are moving slowly and under control, but in the excavated channels elsewhere through which they pass at speed, and where, if the width is insufficient, groundings are likely to happen, and if the sides are rocky and rough, serious injury to the ship will probably result.

What has been said above as to the relative danger to ships in locks and in narrow channels is equally true in regard to delays. From the records of the Suez Canal there was obtained for the first Isthmian Canal Commission a statement showing delays to traffic from ships grounding during a period of eight months, from January to August, 1899, inclusive. No delay of less than six hours was included. Groundings of more than six hours were 15 in number, the aggregate delays to the grounded ships being 292 hours 29 minutes. In 14 of the 15 cases the channel was blocked so that other ships could not pass, the total time during which the canal was blocked being 185 hours 46 minutes. In Appendix S is given a record of delays in the locks of the St. Marys Falls Canal. This is complete for the two locks now in operation in the United States canal since they were opened to navigation.

With duplicate locks, as proposed for the Panama Canal, navigation would seldom be delayed at the locks, as it would be extremely improbable that both of them would be out of use at the same time. In the same appendix information is also given respecting delays to navigation in the excavated channels of the St. Marys and St. Clair rivers. These channels are much wider than the sea-level canal would be, yet they have been blocked on several occasions. Only a small part of the loss to navigation was borne by the vessels causing the blockade. In one instance, when the blockade continued for five days, 332 vessels were delayed, and the loss to navigation amounted to a large sum, estimated to be $600,000. The loss in such a case increases very rapidly with the density of the traffic. In comparing the two projects it must be kept in mind that the broad channels and duplicate locks make a blockade almost impossible on the summit-level canal, while the narrow waterway of the sea-level canal is far more liable to interruption.

If the sea-level canal should be built as now planned it would serve only a temporary purpose; a strong demand would arise within a few years for a broader and safer channel. This demand, we believe, would be made much sooner than any demand for a material change in the summit-level canal built as herein recommended.

It is not intended in this discussion of the relative safety of and delays to ships in the two canals to give an impression that ships will be subjected to a high degree of hazard or delay in either, but to show that the summit-level canal is superior in both respects. The sea-level canal could be made equal to or better than the other by widening the channels a sufficient amount, but the cost of this would be very great.

LAND DAMAGES.

The extensive lakes proposed in the plans of both the lock and sea-level canals will flood large areas of land, a part of which is not owned by the United States. The total area of lakes in the lock-canal plan is 118 square miles, and in the sea-level canal plan 44.6 square miles. The United States owns large areas of land in the Canal Zone formerly owned as follows:

	Square miles.
By the Panama Canal Company	52.11
By the Panama Railroad	55.25
By the Republic of Panama	188.91
Total	296.27
Total area of the Canal Zone	435.50
Private ownership within the Canal Zone	139.23

In addition to the land owned by the United States in the Canal Zone there are, outside of the Zone, Panama Railroad lands having an area of 12.87 square miles.

Of the 118 square miles of lake surface in the lock-canal project 58 square miles within the Canal Zone are owned by the United States, leaving 32 square miles, or 20,480 acres, of private

ownership in the Zone, and 28 square miles, or 17,920 acres, of land belonging to the Republic of Panama or to private owners outside of the Zone.

There are statistics which show that the land purchased by the Panama Canal Company during the early part of the work and subsequently transferred to the United States, as above stated, cost the company an average price of $9.20 per acre in silver, equivalent at the time of purchase to $7.70 per acre in gold. In ascertaining this price per acre the Administration Building, situated in the central portion of the city of Panama, and the land on which it stands, were excluded, but all other lands and buildings were included.

The land which was purchased was located for the most part along the line of the canal and in the vicinity of the Panama Railroad, while the land to be flooded by the lakes and not now owned by the United States is located for the most part at a considerable distance from the railroad. Such land is accessible only on or near rivers which are navigable by canoes, because there are no roads on the Isthmus, and the inaccessible land is practically worthless jungle. Along the rivers there are in places banana lands which have been cleared and are estimated to have a value of at least $50 per acre.

We have not sufficient information for making a close estimate of the value of the lands to be flooded. The accessible lands are probably worth more at the present time than when the purchases were made by the canal company; but, on the other hand, most of the land required is inaccessible and nearly worthless, and it is probable that much of the land outside of the Canal Zone belongs to the Republic of Panama, which has by treaty granted to the United States the right to use it where needed for the purposes of the canal. An approximate estimate may therefore be based on the price per acre paid by the canal company for the whole area it acquired, and such an estimate would be 38,400 acres at $7.70 per acre, making the total cost $295,680, or, in round numbers, $300,000. While the actual cost is likely to exceed this somewhat, no better data for an estimate exist. It would be neither good judgment of values nor to the interests of the United States to submit an extravagant figure.

RELOCATION OF THE PANAMA RAILROAD.

Any plan for the canal requires the relocation of some portion of the Panama Railroad. The Isthmian Canal Commission of 1899–1901 made a plan and estimate for the relocation of the railroad from Bohio to Pedro Miguel, and these have been adopted for this report. In addition it is necessary in connection with the plan herein presented to provide for the relocation of the railroad from a point between Mindi and Gatun to Bohio, and from Pedro Miguel to Panama.

Between Mindi and Gatun recent surveys show that the work will not be particularly heavy or expensive. Between Gatun and Bohio no recent or complete surveys are available, but the information at hand is sufficient to show that a reasonably direct line crossing the lake and taking advantage of the support afforded by the high lands along the route is preferable to one going around the lake. There will be some heavy work along this line at the crossing of the Gatun and other valleys, the maximum height of embankment being about 80 feet, which is not unusual in railroad construction.

From Pedro Miguel toward Panama the railroad may be located without special difficulty around the margin of Sosa Lake until the northerly end of the Ancon-Corozal dam is reached, and it can then run along this dam, which furnishes a nearly direct route to Panama.

For the ten miles of relocation required between Mindi and Bohio, $2,000,000 have been included in the estimate, and for the six miles between Pedro Miguel and Panama, $400,000 have been so included. The estimate of the Isthmian Canal Commission of 1899–1901 for 24.5 miles from Bohio to Pedro Miguel is, in round numbers, $1,300,000, making the total estimated cost of the relocation of the railroad $3,700,000.

ESTIMATED COST FOR PROJECT RECOMMENDED.

An abstract of the estimated cost of the canal with summit level at elevation 85, using the unit prices adopted by the Board, is as follows, full details being presented in Appendix T:

	Miles.	Cost.
Breakwaters in Limon Bay		$5,300,000
Channel in Limon Bay	1.55	1,245,000
Limon Bay to Gatun locks	2.60	3,921,000
Gatun locks, including excavation and back filling	.59	15,691,000
Approach walls to Gatun locks		500,000
Gatun dam and spillway		7,788,000
Gatun to Obispo	23.51	5,005,000
Obispo to Pedro Miguel	8.13	43,337,000
Pedro Miguel locks, including excavation and back filling	.23	6,988,000
Approach walls to Pedro Miguel locks		300,000
Pedro Miguel to Sosa locks	5.47	420,000
Sosa locks, including excavation and back filling	.41	13,092,000
Approach walls to Sosa locks		450,000
Sosa locks to deep water in Panama Bay	4.23	1,939,000
La Boca dam		1,675,000
Ancon-Sosa and Ancon-Corozal dams		1,645,000
Diversion channels between Obispo and Pedro Miguel		850,000
Diversion channel and regulating works at Ancon		275,000
Diversion of Panama Railroad		3,700,000
Movable dams at ends of summit level		2,000,000
Land damages		300,000
	49.72	116,421,000
Administration, engineering, and contingencies, but not including interest during construction, sanitation, or expenses of Zone government		23,284,200
Total estimated cost		139,705,200

Neither the foregoing estimate nor that for the sea-level canal contains an allowance for the fortification of the route.

The total amount of excavation from the canal prism is 95,955,000 cubic yards, of which 53,765,000 cubic yards are from the Culebra cut. The cross sections of the canal used in computing excavation are shown on Plate X.

An allowance of 20 per cent for administration, engineering, and contingencies is provided, as in the Board's estimate for the sea-level canal. In the estimates of the Isthmian Canal Commission of 1899–1901 the same allowance was made, but this allowance was to cover somewhat different items. The allowance in the present estimates does not cover sanitation and Zone government, which were included in the allowance in the former estimate, but does include another item which may prove to be a large one, viz, revetments of the sides of the canal in the Culebra cut.

In the project of the Commission of 1899–1901 the concrete retaining wall was to extend the entire length of the narrow section through the Culebra cut, which, in the plans of that Commission, was 7.91 miles, and was estimated to cost, exclusive of the 20 per cent allowance, $9,619,304. It is now believed that for a large part of the distance through the Culebra cut the rock sides will be sound enough to stand vertical and remain smooth if properly formed by channeling machines, and where this is the case a revetment will not be required, while for the remaining distance some form of revetment will be necessary; it is also believed that the extent and best form of revetment can only be determined by a study of the materials actually seen in place as the excavation proceeds, and that items of this character are appropriately considered as contingencies. It should be pointed out that the cost of revetment on the sea-level canal would be greater than for the summit-level canal by the reason of the greater length of narrow section in the former. In the plan for a summit-level canal the length of the narrow section is reduced to 4.70 miles by widening to 300 feet at each end, while in the sea-level canal there would be 19.47 miles of channel 200 feet wide excavated partly or wholly in rock.

COST OF MAINTENANCE AND OPERATION.

In a comparison of the cost of maintenance and operation of a lock and of a sea-level canal there is in the case of the lock canal the additional cost of the force for operating the greater number of locks, and in the sea-level canal the extra cost of the force which must be kept at the meeting places where ships are moored, and of dredging the canal and diversion channels to maintain their depths.

The lock canal will have locks at three places, each of which will require a force of attendants, while the sea-level canal will have only one such place. On the other hand, there will be no specially prepared meeting places for ships on the lock canal except at the locks, while on the sea-level canal seven such places will be required, assuming them to be five miles apart, and the force required to attend to ships mooring at these places will to a considerable extent offset the extra force required at the locks of the lock canal. To maintain the depth and size of the 40 miles of sea-level canal between shore lines, and of the still greater length of diversion channels, will entail a greater annual expense, as the canal and channels are designed to receive directly the silt of all tributary streams on which dams are not to be built. The lock canal will cost very little for the maintenance of its channels between shore lines, because nearly all the streams empty into lakes where the silt will settle far from the canal. Any dredging required to maintain harbor channels will be common to both plans.

This brief analysis indicates that the sea-level canal will cost no less for maintenance and operation than the lock canal, and this view is supported by estimates given below in detail of cost of maintenance and operation of the two types of canals.

In connection with former projects two methods have been used for estimating the cost of maintenance and operation. The first in point of time was that developed by the French company, based on experience at the Suez Canal, but modified to meet the conditions at Panama; the second was that on which the estimate of the first Isthmian Canal Commission was based.

The estimate of the French company included allowances for (1) central administration in Paris, which it is here assumed would be the same for central administration in the United States; (2) general expenses for meetings, printing, etc.; (3) hospital expenses; (4) administration on the Isthmus, including salaries, office and traveling expenses, pilotage, and all other expenses of operation incurred on the Isthmus, and (5) maintenance, taken at seven-tenths of one per cent of cost of excavation, one per cent of cost of masonry, five per cent of cost of gates and other mechanical structures, and one per cent of cost of dam, diversion channels, etc. The foregoing items are carried into the present estimate without change.

The French estimate contained allowances for taxes, agency at Bogota, etc., not required with United States ownership and not included in the present estimate, but did not provide for maintenance of breakwaters, for which one-half of one per cent of cost is now taken; for maintenance of approach walls to locks, for which two per cent of cost is now taken, or for the government of the Canal Zone, for which the cost as estimated by the first Isthmian Canal Commission is now taken.

The estimate of the first Isthmian Canal Commission was arrived at by outlining an organization for the government of the Zone and the maintenance and operation of the canal, together with an allowance for general expenses in the United States. The details are given in Senate Document No. 253, part 2, Fifty-seventh Congress, first session, pages 693 to 698, inclusive. The allowances made in that estimate are accepted here except as changes are required on account of greater or less number of locks and passing places and greater or less magnitude of the work to be maintained. The allowances for maintenance of excavation, dams, breakwaters, and all constructions except masonry and metallic structures, were made from an estimate of the cost of maintaining and operating an adequate dredging plant and repair force, while other items were provided for by percentages on cost, as follows: Masonry, one-half of one per cent; lock gates, sluices, machinery, etc., seven and one-half per cent.

These two methods are the best thus far proposed, and the results of both will be compared. The amounts will first be given for the summit-level canal herein recommended.

Estimated annual cost of maintenance and operation of the canal with summit level at elevation 85.

I. By the method adopted by the French company:		
Central administration in the United States		$140,000
Government of the Canal Zone		348,480
General meetings, printing, etc		40,000
Hospitals		40,000
Administration on the Isthmus		543,000
Maintenance—		
$\frac{7}{10}$ per cent cost of excavation	$450,055	
1 per cent cost of masonry	325,845	
5 per cent cost of gates, etc	402,150	
1 per cent cost of dams, diversion channels, etc	121,212	
$\frac{1}{2}$ per cent cost of breakwater	31,800	
2 per cent cost of approach walls to locks	30,000	
		1,361,062
Total		2,472,542
II. By the method used by the Isthmian Canal Commission of 1899–1901:		
General expenses in the United States		100,000
Governor's department		39,300
Engineer department		1,053,697
Transit department		351,340
Medical department		104,860
Finance department		27,300
Law department		15,300
Police department		251,100
		1,942,897
Add 20 per cent		388,579
Total		2,331,476

Mean of the two estimates, $2,400,000.

For the sea-level canal there would be no change in the method of the French company except in maintenance, where the same rates would apply as in the preceding case. In applying the method of the first Isthmian Canal Commission no changes would be made excepting in the engineer and transit departments. It seems probable that in the narrow sea-level canal, with a depth nowhere exceeding 40 feet, the annual cost of dredging would be at least twice as much as in the lock canal, where only about 15 per cent of the length is less than 300 feet wide and more than 80 per cent is 45 feet or more in depth. In the transit department the cost will be changed by reducing the number of lock attendants; but there must be, as at the Suez Canal, attendants at each of the passing places. With these changes the following results are obtained:

Estimated annual cost of maintenance and operation of the sea-level canal.

I. By the method adopted by the French company:		
Central administration in the United States		$140,000
Government of the Canal Zone		348,480
General meetings, printing, etc		40,000
Hospitals		40,000
Administration on the Isthmus		543,000
Maintenance—		
$\frac{7}{10}$ per cent cost of excavation	$1,512,000	
1 per cent cost of masonry	72,869	
5 per cent cost of gates, etc	66,600	
1 per cent cost of dams, etc	63,358	
$\frac{1}{2}$ per cent cost of breakwaters	30,000	
2 per cent cost of approach walls to locks	19,080	
		1,763,907
Total		2,875,387

II. By the method used by the Isthmian Canal Commission of 1899–1901:

General expenses in the United States	$100,000
Governor's department	39,300
Engineer department	652,932
Transit department	343,060
Medical department	104,860
Finance department	27,300
Law department	15,300
Police department	251,100
	1,533,852
Add 20 per cent	306,770
Total	1,840,622

Mean of the two estimates, $2,360,000.

The large discrepancy between the two estimates is due principally to difference in the estimated cost of maintaining an excavated channel, the French estimate being based on experience at Suez and calculated to be proportional to the cost of excavating the canal. The estimate arrived at by following the method of the Isthmian Canal Commission is based on the cost of operating the dredging plant, and the number of dredges required may be underestimated. The correct amount probably lies between the two estimates, and if the mean be taken as above the estimated cost of maintenance and operation is practically the same for both projects.

SAFETY OF DAMS.

The Board in its discussion of types of dams has expressed many apprehensions of grave dangers to be feared on account of the character of the material on which it has been proposed to place dams at the Isthmus. A due consideration of each case by itself, giving proper weight to the character and location of the materials disclosed by the borings and to the adequacy of the design, would show that these apprehensions are unnecessary in regard to the dams herein proposed.

Reference is made in the Board's discussion to the subsurface material at Gatun, which is stated to be "in large part of a comparatively fine character, consisting of sand and clay in varying portions and in various degrees of admixture, but the borings have also shown coarse sand and gravel."

In order to make this statement express clearly the actual situation the addition should be made that the coarse sand and gravel are found in the bottom of the narrower of the two deep gorges in the rock, and overlying them are 200 feet in thickness of finer materials, the impervious character of which will prevent the waters in the lake from having access to this deep-lying sand and gravel in any appreciable quantity. In view of these conditions at the site of the Gatun dam, and the great width of one-half mile which has been given its base in the proposed design, we can not concur in the view expressed that "it is more than possible, it is highly probable if not certain, that at various points the material is sufficiently loose in texture to permit seepage or percolation in dangerous quantities." Actual experience with dams and experiments on the filtration of water through sand and finer materials show that the amount of water filtering under such circumstances will be too small to affect in any way the stability of the dam. Neither do we concur in the statement that "nothing is more common in the sandy deposits of river valleys and in all sandy material than small passages or channels through which water moves, varying in size from thread-like openings to those sufficient to yield flowing wells of large discharge," because there is nothing in our experience to support this view, nor does it seem that such passages or channels could possibly be formed or maintained in a saturated granular material.

The subsurface sands on the southerly slope of Long Island, from which a portion of the water supply of the borough of Brooklyn is taken, and to which the Board refers, are noted for their extent and for their porosity, due to the size and uniformity of their grains.

By far the larger part of this water supply is taken from the Ridgewood system of works,

which comprises both surface and subsurface sources. The quantity taken from the ground equals approximately 70 cubic feet per second, a volume which is small in comparison with the 1,477 cubic feet per second available for lockage in the canal plan recommended. This quantity, however, is collected in a length of 21.3 miles, so that the quantity per mile is only about three and one-half cubic feet per second, or, in a length equivalent to that of the Gatun dam, about five and one-half cubic feet per second. If instead of using the total length of the Gatun dam, only the parts of the length which cross the alluvial valleys were included, the proportionate quantity would be still smaller. If any inferences of value are to be drawn from a comparison of conditions at Long Island with those at the dam sites at the Isthmus, where clay is the predominating material, they are that even under conditions favorable to filtration the amount of water passing through a considerable length of ground is comparatively small, and that water may filter through and be taken from the ground without disturbing either the earth through which it filters or that from which it is taken.

The extent of the sand and gravel deposit in the lower part of one of the rock gorges at Gatun is limited, and if it be assumed that instead of being covered with an impervious blanket 200 feet thick the water above and below the dam has free access to the porous material, and if the further assumption be made that the material has as much filtering capacity as a coarse uniform sand or a coarse unscreened gravel or a typical Long Island sand, the quantity of water which would pass through it would be very much restricted by the long distance covered by the dam, and would not exceed two cubic feet per second.

The borings at the site of the La Boca dam indicate impervious mud and clayey material, and show no sandy material overlying the rock, as stated in the report of the Board, so that the introduction of a masonry core or other stop-water appears from present information to be unnecessary. The earth dam as proposed will be in no "danger of being pushed bodily out of place by the pressure due to the head of water in the reservoir," because it has been made very massive, conforming in this respect to the suggestions of the Board made since the dam was designed.

At the great north dike or embankment of the Wachusett reservoir, referred to by the Board, porous material was removed and replaced by fine and impervious material, and sheet piling was driven where seepage or percolation was apprehended, but at the other parts of the dike where there were no such apprehensions the impervious material of the embankment was placed directly on the impervious earth found at the site of the dike. Should any safeguards prove necessary to prevent seepage, when detailed investigations are made at the Isthmus, it is expected that they will be provided, and to cover any probable expenditure for this purpose an allowance of $400,000 for all dams has been included in the estimates.

The construction of earth dams to retain water 85 feet deep is not an untried experiment, as there are many earth dams of equal or greater height, nearly all of them made wholly of earth without a masonry core, and none of them having nearly the mass or the stability of those herein recommended.

CONCLUSIONS AND RECOMMENDATION.

The greater cost of the proposed sea-level canal—upward of $100,000,000 more than that of the lock canal herein advocated—is not a trifling sum, even for the resources of the United States. If such an outlay is incurred a greatly superior waterway should be obtained or the expenditure will be unwise and the result discreditable.

The question of relative safety of the two types of canal must be considered with reference both to the waterway and the traffic. Accidents to the waterway may stop traffic or may only retard it or may not affect it at all, depending on the nature of the accident.

There can be no doubt that the greater the number of locks the greater the risk of injury to some one of them. It has been shown that the risk of serious injury to a well-equipped canal lock has been found very small, and with the additional and unusual precautionary constructions

proposed for the lock canal at Panama it will be almost inappreciable, except in time of war. At such a time either form of canal would require efficient military protection, and such protection is as practicable for a lock canal with a broad waterway as for the narrow channel of the sea-level canal. In the former case military protection would be specially required at the locks and in the narrow portion of the Culebra cut; in the latter case, the advantage of a smaller number of locks to be guarded would be fully offset by the greater difficulty of guarding the entire length of narrow channel, which would extend from sea to sea.

It has been shown by ample experience that ships are far more liable to delay and injury while traversing artificial channels at considerable speed than when passing locks where they move slowly and are under perfect control. The narrower the channel the greater the danger of collisions, groundings, blockades, and injuries to ships.

The broad channels of which the lock canal will mainly consist will permit vessels to move at greater speed than would be safe in a narrow channel. Although the Board apparently questions this, its truth is self-evident and, moreover, is established beyond a doubt by abundant and long-continued experience. Ships meeting in these broad channels will pass in safety with little if any reduction of speed, while in the narrow sea-level canal one of two meeting ships, unless of small size, would have to stop and make fast to the bank at a regular meeting place and remain there until the other passed at reduced speed, involving both delay and appreciable risk to the ships.

In consequence of the lower speed and the delays of various kinds in the narrow sea-level canal, ships of large size would consume more time in passing through it than would be required in a lock canal, and with a heavy traffic this would be true for ships of even moderate size, for the reason that more time would be lost in the narrow channel of the former than at the locks of the latter. As the delays at meetings in the sea-level canal would increase rapidly with the traffic, they would become insupportable with a traffic much smaller than the lock canal would provide for. The sea-level canal may therefore be called "provisional" with far more propriety than the lock canal.

The difficulty apprehended by the Board in the passage through locks of large ships, especially of large war ships, would doubtless be realized if the locks were no better equipped than in some well-known ship canals. Long approach walls with vertical faces, where a ship can be checked and stopped at a safe distance from the lock, against which it can lie and along which it can move safely with lines out, are indispensable for the safe operation of a lock. When these are provided there are no special increasing risks as the ship dimensions increase. This is fully shown by experience where such approaches exist.

The summit level of the lock canal and the terminal lake on the Pacific side are to be held up by earth dams supporting less heads of water than many existing earth dams, but of unprecedented strength both in regard to width and to height above the water surface. Only the facility with which these dams can be built and the great importance of making them secure beyond a shadow of doubt justify dimensions so extraordinary in proportion to the height of water to be sustained.

We believe the locks and other structures of the lock canal can be built in less time than is required for the Culebra cut, but the margin is not great and the project is well balanced in this respect. If the summit level were made higher the Culebra cut could be completed sooner, but the locks would require more time and the canal would probably not be finished as soon; if the summit level were made lower the Culebra cut would obviously take longer. We believe, therefore, that the project we recommend will open navigation across the Isthmus in the least possible time. Since the Culebra cut will fix the time for completing either the lock canal or the sea-level canal, and the former requires only half as much excavation from the Culebra cut as the latter, it can be built in approximately half the time. A difference of six years in favor of the lock canal is a very conservative estimate.

In view of the unquestioned fact that the lock canal herein advocated will cost about $100,000,000 less than the proposed sea-level canal; believing that it can be built in much less time; that it will afford a better navigation; that it will be adequate for all its uses for a longer time, and can be enlarged, if need should arise, with greater facility and less cost, we recommend the lock canal at elevation 85 for adoption by the United States.

Respectfully submitted.

ALFRED NOBLE.
HENRY L. ABBOT.
FREDERIC P. STEARNS.
JOSEPH RIPLEY.
ISHAM RANDOLPH.

APPENDIXES.

THE BOARD OF CONSULTING ENGINEERS FOR THE PANAMA CANAL.

Appendix A.

MINUTES OF THE PROCEEDINGS OF THE BOARD.

FIRST MEETING.

Washington, D. C., *September 1, 1905.*

The meeting was called to order at 10 a. m. by the Chairman, Gen. George W. Davis.

The Chairman announced that Capt. John C. Oakes, General Staff, U. S. Army, had been detailed by the War Department to act as Secretary to the Board.

The Secretary called the roll, the following members responding:

Gen. George W. Davis, Chairman, Mr. Alfred Noble, Mr. Wm. Barclay Parsons, Mr. Wm. H. Burr, Gen. Henry L. Abbot, Mr. Frederic P. Stearns, Mr. Joseph Ripley, Mr. Isham Randolph, Mr. W. Henry Hunter, Mr. Adolphe Guérard, Mr. Edouard Quellennec, and Mr. J. W. Welcker. Mr. Eugen Tincauzer arrived toward the end of the session.

The Chairman read, for the information of the Board, the executive order of the President of the United States convening Board of Consulting Engineers, as follows:

EXECUTIVE ORDER.

It is hereby ordered that a Board of Consulting Engineers, consisting of—

General George W. Davis,
Mr. Alfred Noble,
Mr. William Barclay Parsons,
Mr. William H. Burr,
General Henry L. Abbot,
Mr. Frederic P. Stearns,
Mr. Joseph Ripley,
Mr. Herman Schussler,
Mr. Isham Randolph,
Mr. Henry Hunter, nominated by the British Government,
Herr Eugen Tincauzer, nominated by the German Government,
M. Guérard, nominated by the French Government,
M. Quellennec, consulting engineer, Suez Canal, and one engineer to be designated by the Government of the Netherlands,[a]

shall convene in the city of Washington, at the rooms of the Isthmian Canal Commission, on the first day of September, nineteen hundred and five, for the purpose of considering the various plans proposed to and by the Isthmian Canal Commission for the construction of a canal across the Isthmus of Panama between Cristobal and La Boca; and that the deliberations of the Board of Consulting Engineers shall continue as long as they may deem it necessary and wise before they make their report to the Commission.

The Isthmian Canal Commission is directed to have all the proposed plans in such detailed form, with maps, surveys, and other documents sufficient to enable the Consulting Engineers to consider and decide the questions

[a] Mr. J. W. Welcker was designated by the Netherlands Government.

presented to them. Should it be deemed necessary by the members of the Consulting Board, they may visit the Isthmus before making their final report. If there is a difference of opinion between the members of the Consulting Board, minority reports are requested.

General George W. Davis is hereby designated as Chairman of the Board of Consulting Engineers. Instructions more detailed will be given in time to be presented to the Board when it first convenes on the 1st of September.

The Chairman is charged with the duty of communicating to the other members of the Board this order and the other details that may be necessary.

THEODORE ROOSEVELT.

THE WHITE HOUSE, *June 24, 1905.*

The Chairman stated that Mr. Herman Schussler, who had been appointed a member of the Board, had, on account of business affairs which prevented his coming to Washington, felt obliged to decline the appointment; also that Mr. J. B. Berry, chief engineer of the Union Pacific Railroad, was compelled to decline an appointment to the Board for the same reason.

The Chairman stated that the Government of the Netherlands first designated for appointment to the Board Professor Kraus, but that a few days subsequent to said appointment this gentleman was called to a position with the Government, which made it impossible for him to accept, and Mr. J. W. Welcker, who was present, was then selected.

The Chairman, on behalf of the President of the United States, extended to the several members of the Board an invitation to visit him at Oyster Bay and to take luncheon at his country residence at such time as might be most convenient, after having effected a complete organization. The details of this visit would be so arranged that the Board, upon arriving in New York in the morning, would take passage on the yacht *Sylph*, at the foot of East Twenty-fifth street, go to Oyster Bay, and return the same day, the return journey being arranged from here.

The Chairman further stated, in this connection, that the Chairman of the Isthmian Canal Commission, Mr. Shonts, had prepared invitations for each member of the Board to a dinner and social talk, etc., at the Chevy Chase Club, Chevy Chase, Md., at 8.30 o'clock that evening, and that Mr. Shonts hoped that the entire Board would be present.

The Chairman then informed the Board that the next step in order was to submit to the Board the documents which, by the President's order, were required to be prepared and offered for their consideration, viz, the various plans and projects which the Isthmian Canal Commission deemed worthy of consideration. He further stated that all the plans, projects, etc., were before the several members of the Board, on the table, in the form of monographs and pamphlets, and that he would proceed to read the letter of transmittal, as follows:

ISTHMIAN CANAL COMMISSION,
Washington, D. C., September 1, 1905.

THE BOARD OF ENGINEERS ADVISORY UPON PLANS FOR THE PANAMA CANAL,
Washington, D. C.

GENTLEMEN: In accordance with the directions of the President, dated April 1, 1905, the Isthmian Canal Commission has the honor to lay before you physical data concerning the Isthmus of Panama, and to solicit your opinion as to the best plan to be followed in the completion of the Panama Canal, within reasonable limits of cost and time.

As you are aware, this question has been the subject of prolonged and elaborate studies for many years by numerous able engineers. A vast amount of labor has been expended in the collection of information concerning the physics of the Isthmus, and in digesting it and formulating it into plans for the canal. The results of all these labors, both in the field and in the office, down to a recent date, are given in the reports of two distinguished Commissions, viz, the Comité Technique, of which the report is dated at Paris, November 16, 1898, and the American Commission of 1899–1901, of which the report is dated at Washington, November 16, 1901. A careful perusal of these reports, and examination of the maps and documents which accompany them, will afford as satisfactory a view of the entire subject, at the dates when they were written, as can now be given. They have been reprinted, each in a separate pamphlet, and in that form are now handed to you, marked "Part I" and "Part II," respectively.

During the last year additional surveys and observations have been made upon the Isthmus, the results of which are laid before you. It may be stated here in general terms that the information which they furnish does not involve any radical change in the plans previously favored. Among the observations alluded to may be included the experience of the last year in excavating the Culebra cut, from which some of our engineers have drawn unwarranted conclusions as to the probable cost of the work. There is nothing in this experience to justify the belief that the unit prices used in previous estimates were too high, or that the estimate of the time required for completing the work was too liberal. Nevertheless, this experience has been used as an argument in favor of a sea-level canal, which plan

had been condemned by the two Commissions mentioned above. It becomes necessary to consider once more the sea-level scheme. The principal information available for a decision as to the merits of that project has been printed in the form of a third pamphlet, which is now handed to you, marked "Part III," and in which will be found the more important results of the recent surveys.

These three pamphlets are commended to your careful consideration. With the large map—scale 1:5,000—of which a copy is also handed to you, it is hoped that a fair idea may be obtained of the conditions on the Isthmus, and of the relative merits of the three plans proposed. There are on file here many other maps, reports, and drawings, any or all of which will be placed at your disposal should there be any point which requires further elucidation.

The plan described in the first pamphlet is the one which was adopted by Congress—at least by inference—in the act approved June 28, 1902. It is the plan under which the work is now progressing, and under which all work of construction has been done since the United States acquired the property. It closely resembles the plan of the Comité Technique, described in the second pamphlet, in many essential particulars, but differs from it in the height of the Bohio dam, and the important results which flow therefrom. The advantages which its authors expected to derive from this change were—

1. To take fuller advantage of the topography of the country, by which it was possible to make the Gigante spillway automatic, instead of mechanical, and adequate for the discharge of the greatest floods, with only one channel to the sea instead of two.

2. To increase the distance of lake navigation from 7 to nearly 13 miles.

3. To reduce the estimated cost of the canal by about $15,000,000.

The disadvantages of the change are the somewhat greater difficulties in constructing the higher dam and the locks of greater lift, difficulties, however, which are by no means insuperable.

A disadvantage which the two plans have in common is that the rapid developments of naval architecture make it difficult to determine the proper dimensions of the lock chambers. It is to be considered, however, that up to the present time such development has not been greatly hampered by deficient depth in the harbors of the world, and that development hereafter will have that obstruction to contend with. Moreover, it is not possible to dispense with locks entirely. Even with the sea-level canal, a tide lock will be required at the Panama end.

In addition to the plans above mentioned, a pamphlet has been prepared by Mr. Lindon W. Bates, which gives in outline a sketch of a plan proposed by him, which is interesting on account of its novelty, and is, therefore, laid before you. It does not give detail enough for a close analysis, nor for estimates of cost. To obtain this, extensive additional surveys, to occupy at least a year's time, would be necessary.

A paper has been submitted to the President by Mr. P. Bunau-Varilla, which explains a method by which a canal constructed at first with locks may be subsequently altered to a sea-level canal. This paper also is submitted for your consideration.

These last two documents are described in a fourth pamphlet, marked "Part IV," which is now handed to you.

It is to be noted that the law by which Congress ordered the construction of an Isthmian Canal contained the following proviso, viz:

"The President shall then, through the Isthmian Canal Commission hereinafter authorized, cause to be excavated, constructed, and comple ed, utilizing to that end, as far as practicable, the work heretofore done by the New Panama Canal Company, of France, and its predecessor company, a ship canal from the Caribbean Sea to the Pacific Ocean. Such canal shall be of sufficient capacity and depth as shall afford convenient passage for vessels of the largest tonnage and greatest draft now in use, and such as may be reasonably anticipated, and shall be supplied with all necessary locks and other appliances to meet the necessities of vessels passing through the same from ocean to ocean; and he shall also cause to be constructed such safe and commodious harbors at the termini of said canal, and make such provisions for defense as may be necessary for the safety and protection of said canal and harbors."

The Commission expects to visit the Isthmus of Panama, sailing from New York during the last week in September, the exact date to be fixed hereafter. You are cordially invited to accompany them.

This method of presenting the subject to you, by offering several well-digested plans, has been adopted because it seemed to be the method by which all essential information could be conveyed in the most condensed possible form. It is needless to say that the Commission desires your opinion not only upon these plans, but upon any variation of them, or upon any entirely different plan which may suggest itself to you. It requests your views as to what plan it is most expedient, all things considered, for the United States to follow in the completion of the Panama Canal.

Yours, very respectfully,

T. P. Shonts, *Chairman.*

The Chairman stated that the task committed to the Board was before its several members in the form in which the Isthmian Canal Commission had elaborated it, four plans being presented for consideration. That the solution of this problem might be said to be the most momentous one that had ever been presented to any similar body of engineers, and a solution would no doubt be reached that would justify the confidence of the President in his action in appointing this Board.

The Chairman then invited discussion concerning the future procedure of the Board, place of future meetings, etc.

Mr. Parsons moved that a committee of five be appointed by the Chairman, of which the Chairman should be a member, for the purpose of considering the rules of procedure of the Board and all kindred subjects, including future meetings, etc., and of making recommendations as to whether the Board should work as a whole or be subdivided into committees, and that this committee report to the full Board this afternoon at 3 o'clock.

The Chairman stated that the city of Washington was selected by the President as the place of meeting; that the Isthmian Canal Commission had set aside these rooms, and that the Chairman of the Commission had mentioned to him the considerations which had caused the Commission to suppose that this city would be the place of meeting; that here were found all the documents, records, and a good many of the persons that might be required in deliberations, testimony, expert advice, etc. The Chairman further stated that he mentioned this more for the information of the gentlemen from abroad than for our own members, because they were not so familiar with these matters.

The Board, not caring to debate further on the subject, unanimously adopted Mr. Parsons's motion.

Thereupon the Chairman selected the following members to form with him the committee: Mr. Wm. Barclay Parsons, Gen. Henry L. Abbot, Mr. E. Quellennec, and Mr. Isham Randolph.

Mr. Shonts, Chairman of the Isthmian Canal Commission, together with Commissioners Endicott, Hains, Harrod, and Ernst, entered the meeting, and were presented to the members of the Advisory Board.

At 10.45 o'clock a. m. the Board took a recess until 3 p. m.

The full Board reassembled at 3.25 p. m.

Mr. Guérard stated that in the name of the foreign members of the Board he desired to extend their respects to the President of the United States. They considered it their first duty to present their compliments to the President, and asked that the Chairman of the Board express their sentiments to President Roosevelt.

The Chairman replied that he would take an early opportunity to communicate the remarks of Mr. Guérard to the President of the United States who, he felt sure, would be extremely gratified at the sentiments expressed, and who, he also felt assured, on the occasion of his meeting with the gentlemen of the Board and especially with the gentlemen who had come from Europe, would avail himself of that opportunity to express his gratitude that he had been able to secure the services of these gentlemen to assist him in the determination of this great question. The Chairman further stated that it would be a great pleasure to communicate to the President the fact that this Board had finally completed its organization, so that he might indicate the day and the time when the members of the Board could wait upon him at Oyster Bay and sit with him at his table at breakfast, which invitation he had instructed the Chairman to extend in his name.

The Chairman then read the report of the special committee which was appointed at the morning session, stating that the same was before the Board for consideration, discussion, and action. The following is the report in full:

SEPTEMBER 1, 1905.

THE BOARD OF CONSULTING ENGINEERS.

GENTLEMEN: The undersigned members of the committee which was appointed at the morning session "for the purpose of considering the rules of procedure of this Board and all kindred subjects, including future meetings, etc., and to make recommendations as to whether the Board should work as a whole or be subdivided into committees," beg leave to report as follows:

The committee recommends that an executive committee of this Board be appointed, consisting of the Chairman of the Board and two members named by him, and charged with duties as follows:

(a) The general business arrangements of the Board.

(b) The determination of questions to be submitted to the Board at each next succeeding meeting, and to make suggestions as to the place to which adjournments should be taken if it should be thought unadvisable to meet in Washington.

It is recommended that for the present one stated meeting shall be held each week, at 10 o'clock a. m., on Tuesdays.

At each meeting the order of business to be—

(a) Roll call.
(b) Adoption of minutes of preceding meeting.
(c) Consideration of such questions as shall be submitted by the executive committee.
(d) The consideration of communications that may have been received.
(e) Motions for action by members.
(f) Adjournment.

At each regular meeting the members of the Isthmian Canal Commission may be present, but otherwise all meetings, unless specially directed, to be executive.

In order to simplify procedure, motions made need not be seconded in order to be considered, and members, when addressing the chair, may remain seated; otherwise ordinary parliamentary rules govern.

Capt. John C. Oakes, U. S. Corps of Engineers and member of the General Staff of the Army, who has been detailed for special duty in connection with this work by the Secretary of War, will act as secretary of the Board of Consulting Engineers, keep the minutes of the same, and in the name of the Chairman send out notices to members.

A special call for a meeting of the Consulting Board of Engineers may be issued by the Chairman upon the request of any two members of said Board.

That in the absence of the Chairman of the Board, the temporary chairmanship to devolve upon the members in succession as their names appear in the executive order creating the Board.

Considering that Washington has been designated by the President as the place of assembly, future meetings will be held in this city, unless the Board shall deem it to be convenient and necessary in the discharge of their duties to meet elsewhere.

Respecting the seggregation of the Board into committees, your committee is of the opinion that such an arrangement of the membership is not required by the necessities of the case, at least at the present time. The first work before the members, which will fully occupy their time at present, is the study of the data now before them; and when these data are under consideration, it would seem better that it should be by the full Board than that consideration should first devolve upon committees.

Unless a programme of the work to be considered is arranged beforehand, much delay and inconvenience would almost certainly result; hence it is that your committee suggests the appointment of an executive committee, whose business it would be to make timely arrangements for consideration of special questions, or branches of subjects, and to see that all requisite data required to elucidate those subjects be in readiness. The arguments in favor of this course seem to be so cogent that a further demonstration of their necessity is hardly necessary.

It seems to the committee proper, or indeed almost certain, that a visit to the Isthmus at an early day, at least by those members who are not familiar with the local conditions, should be arranged for. Supposing that only a partial membership of the Board is on the Isthmus, no formal meetings will be held there, but hearings of those familiar with local conditions would take place and the action of those members of the Board present would be confined to these hearings and to the collection of data.

Respectfully submitted.

GEO. W. DAVIS.
WM. BARCLAY PARSONS.
HENRY L. ABBOT.
E. QUELLENNEC.
ISHAM RANDOLPH.

I have signed the above report, which represents my views except that I believe New York should be selected as the regular place of meeting. The canal will be a great commercial highway, and in New York are located the corporations and men engaged in transportation, and also contractors and manufacturers of machinery. The Board should be so situated as to be in close touch with such men and records. The work of this Board will be facilitated with New York, rather than Washington, as headquarters.

WM. BARCLAY PARSONS.

The Board then took up the subject of the periodicity of its meetings, and also the place of holding future meetings.

Objection was first made to that part of the report which required the formal meetings to occur once per week, the point being made that under such circumstances the work would be retarded and prolonged indefinitely. After statements by General Abbot and others as to the reasons for this provision, and also the statement that it was generally understood that the meetings could be adjourned from day to day, and that special meetings could be called when there was warrant for such action, the discussion was closed.

The consideration of the location at which future meetings will be held brought forth a lengthy discussion.

Mr. Parsons moved that the recommendation in the report as to the place of regular meetings be amended as follows:

Resolved, That Washington be the place of the meetings up to the time when the Board goes to the Isthmus, and that after its return, New York be the place, except that the first meeting next after the return from the Isthmus, and also the last meeting of the Board, be held in Washington.

The preceding report, with Mr. Parson's amendment, was adopted by the Board.

The Chairman stated that inasmuch as the report of the special committee had been adopted, he would designate General Abbot and Mr. Hunter to act with him as the Executive Committee.

The Chairman asked for the views of the Board on the advisability of permitting representatives of the press to have access to the meetings.

After discussion it was decided that it would be injudicious to have the meetings open to representatives of the press, but that at the close of each session the Chairman should prepare a memorandum of what had transpired in the day's session that might be deemed proper to be given to the press; this memorandum to be placed on the bulletin board.

The Chairman stated that the Executive Committee would at once take up its work, and when it had decided on a subject for discussion at the next meeting the members would be notified beforehand, that they might come prepared for such work. He further stated that the Executive Committee might meet early and have a report ready for the Board by 11 a. m. to-morrow.

Motion was made and carried to adjourn, to meet to-morrow at 11 a. m.

JOHN C. OAKES,
Captain, General Staff, Secretary.

SECOND MEETING.

WASHINGTON, D. C., *September 2, 1905.*

The meeting was called to order at 11 a. m. by the Chairman.

Present: The CHAIRMAN, and Messrs. NOBLE, PARSONS, BURR, ABBOT, STEARNS, RIPLEY, RANDOLPH, HUNTER, TINCAUZER, GUÉRARD, QUELLENNEC, and WELCKER.

As the minutes of the preceding meeting were not ready for distribution the reading was postponed until later.

The Chairman of the Board then announced that the Executive Committee submitted the following as the subject for discussion and study at the next formal meeting:

The Executive Committee recommends that during the interval between adjournment and the next meeting the members examine the documents before the Board and prepare to discuss the general dimensions to be given to the canal, including the locks, to meet the requirements of the law of Congress authorizing the canal.

It is also suggested that the Isthmian Canal Commission be requested to furnish the Board with a list of the important commercial harbors of the world, and the navigable depth at their entrances.

An amendment was proposed to the above, by adding after the word "entrances" the following:

Together with recent progress in increasing such depth; also the dimensions of the largest ships recently built and now in process of construction, including vessels of war, and indicating the classes of traffic which they are intended to serve.

After discussion, the recommendations of the Executive Committee, together with the amendment, were adopted by the Board.

The Secretary then read the minutes of the first meeting, which were adopted.

It was suggested that there should be uniformity in the official designation of the Board, and recommended that the Board adhere to the designation given by the President of the United States, namely, "The Board of Consulting Engineers."

This suggestion met the approval of the entire Board.

The meeting adjourned at 11.55 a. m., subject to the call of the Chairman.

JOHN C. OAKES,
Captain, General Staff, Secretary.

THIRD MEETING.

WASHINGTON, D. C., *September 8, 1905.*

The meeting was called to order at 10 a. m. by the Chairman.

Present: The CHAIRMAN, and Messrs. NOBLE, PARSONS, BURR, ABBOT, STEARNS, RIPLEY, RANDOLPH, HUNTER, TINCAUZER, GUÉRARD, and WELCKER. Mr. QUELLENNEC arrived directly after roll call.

The Secretary read the minutes of the preceding meeting, which were adopted.

After a brief discussion it was the sense of the Board that informal suggestions made during the course of the meetings should not be incorporated in the minutes with the author's name, but that all formal motions should be recorded, with the name of the member offering the same.

The Chairman stated for information that the data concerning the depths of important harbors of the world and the sizes of the largest ships, etc., which the Board at its last meeting requested the Isthmian Canal Commission to obtain, were not yet prepared, but that the same would probably be furnished the Board at its next session.

Mr. Guérard read for the information of the Board a paper he had prepared relative to the depths of harbors of the world and sizes of ships. (See Appendix C.)

On motion it was resolved that each member of the Board be provided with a typewritten copy of Mr. Guérard's paper.

The Chairman stated that the next business in order would be the consideration of a set of resolutions which the Executive Committee had drafted, a copy of which had been furnished each member. The resolutions follow:

(1) *Resolved*, That, leaving out of consideration the harbors, the Board approves the location and curvatures of the canal as shown on the maps of the two projects before it, which are practically identical in these respects.

(2) *Resolved*, That the Board considers that while, under the terms of the law, provision must be made for "convenient passage for vessels of the largest tonnage and greatest draft now in use, and such as may be reasonably anticipated, and shall be supplied with all necessary locks and other appliances to meet the necessities of vessels passing through the same," this language does not imply that provision shall be made to enable vessels of very exceptional size, such as will probably rarely pass the canal, to attain the maximum speed usually permitted to secure the slopes against injuries, that is to say, a speed of 6 miles (10 km.) per hour. To do so, as estimated at the Navigation Congress which assembled at Brussels in 1898, would demand a cross section four times the maximum midship cross section of the ship. It will be sufficient to apply this rule to the largest vessels usually passing the canal, having a draft of 26 feet (8 m.) and a midship beam of 65 feet (20 m.). The minimum cross section of the canal may then be estimated by deducting 10 per cent from the product of draft and beam and multiplying the result by 4; which in figures calls for 6,084 square feet, say 6,100 square feet (567 m².). It is the opinion of the Board that this should be the minimum limit, except at the locks, where other considerations should govern.

(3) *Resolved*, That the minimum depth in the canal should be 35 feet, and the minimum width at bottom should be 150 feet.

(4) *Resolved*, That, leaving out of consideration the deep cut at the Culebra, in accordance with the conclusions reached at the Navigation Congress at Brussels there should be a horizontal berm 10 feet (3 m.) in width placed about 8 feet (2.5 m.) below the water surface on each side of the canal; that the slope of the sides should depend on the nature of the material, ranging from about 3 on 2 in rock to about 2 on 3 in ordinary earth, and about 1 on 3 in submerged sections or very soft earth. That the slopes above the berm should be revetted to a height of about 7 feet (2 m.) above the water.

After discussion, the first resolution was amended to read as follows:

(1) *Resolved*, That, leaving out of consideration the harbors and locks and the portions of the canal adjacent thereto, the Board approves the general location of the center line of the canal as shown on the maps of the two projects before it, which are practically identical in these respects.

The resolution as amended was adopted.

Mr. Stearns offered the following amendment, which was adopted:

Resolved, That until otherwise voted, resolutions relating to the design of the canal be regarded as provisional expressions of the views of this Board.

The following resolution, offered by Mr. Parsons, was next adopted:

Resolved, That the Executive Committee be requested to lay before the Board the main dimensions of cross sections, depth, width, curvature, etc., of the large ship canals of the world, or any pending alterations thereof, and the similar dimensions of the Panama Canal as prepared by the Commission of 1899–1901; and that the members of the Board familiar with the above canals be requested to furnish the committee with the above data.

The Board then considered the second resolution submitted by the Executive Committee. After discussion the resolution was amended as follows, and adopted:

(2) *Resolved*, That the Board considers that while, under the terms of the law, provision must be made for "convenient passage for vessels of the largest tonnage and greatest draft now in use, and such as may be reasonably anticipated, and shall be supplied with all necessary locks and other appliances to meet the necessities of vessels passing through the same," this language does not imply that provision shall be made to enable vessels of very exceptional size, such as will probably rarely pass the canal, to attain the maximum speed usually permitted, that is to say, a speed of 6 miles (10 km.) per hour. To do so, as estimated at the Navigation Congress which assembled at Brussels in 1898, would demand a minimum cross section four times the maximum midship cross section of the ship. It will be sufficient to apply this rule to the largest vessels which will usually pass the canal. The minimum cross section of the canal may then be estimated by deducting 10 per cent from the product of draft and beam and multiplying the result by 4.

At 1 p. m. the Chairman announced that the Board would take recess, and report again at 3 p. m.

At 3.05 p. m. the Board reassembled, all the members being present.

Mr. Noble read for the information of the Board a paper which he had prepared giving his views on the subject of dimensions of ships and the use of the proposed canal by shipping.

The following resolution was submitted by Mr. Parsons, and adopted:

Resolved, That the Secretary be authorized to have the minutes of the Board, together with all written documents pertaining thereto, printed and delivered to the members as soon as possible after they have been approved by the Board; also that all papers submitted by the foreign members be properly translated.

The Chairman stated that it was in order to consider the third resolution offered by the Executive Committee, as follows:

(3) *Resolved*, That the minimum depth in the canal should be 35 feet, and the minimum width at bottom should be 150 feet.

The above resolution was adopted without amendment.

The fourth resolution of the Executive Committee was considered, and, after discussion, Mr. Welcker presented the following in its stead, which was adopted by the Board:

(4) *Resolved*, That, leaving out of consideration the deep cut at the Culebra, in accordance with the conclusion reached at the Navigation Congress at Brussels there should be a horizontal berm of such width and height, and a slope above the berm, as shall be proven adequate to each location at the time of execution; that the slope in rock shall be as nearly perpendicular as possible, if not almost vertical; that, however, for the purpose of making estimates—but only for that purpose—the Board shall suppose the construction of a horizontal berm 10 feet in width, placed about 6 feet below the water surface, with slopes above the berm revetted to a height of about 7 feet above the water level.

The Chairman stated that the Executive Committee recommended that at the next stated session the Board take under consideration the conditions affecting the construction of dams, with a view to preparing for future studies of which they form important elements.

It was moved that the Chairman inform Mr. Lindon W. Bates that the Board would hear him on the subject of his projects at 60 Wall street, New York City, on Tuesday, September 12, at 10 a. m., and would accord him the time until 1 p. m.

The motion was carried.

The Board adjourned at 5.25 p. m., to meet at 60 Wall street, New York City, on Tuesday, September 12, at 10 a. m.

JOHN C. OAKES,
Captain, General Staff, Secretary.

FOURTH MEETING.

60 WALL STREET, NEW YORK CITY, *September 12, 1905.*

In accordance with the resolution passed at the last regular meeting, the Board met at 60 Wall street, New York City, at 10 a. m.

Present: The CHAIRMAN and Mr. PARSONS.

There being no quorum present, the meeting adjourned to meet in Washington on Friday, September 15, at 10 a. m.

As the object of this meeting held at New York was to afford Mr. Lindon W. Bates an opportunity to come before the Board and present the different aspects of his project for the Panama Canal, and as subsequent to the adjournment of the third meeting information had been received from Mr. Bates that he would be unable to present his plans at the designated time, an informal announcement had been made to the members of the Board to the effect that it would be unnecessary for them to be present at this meeting, as there was no other business to come before them; hence the lack of attendance by members of the Board.

JOHN C. OAKES,
Captain, General Staff, Secretary.

FIFTH MEETING.

WASHINGTON, D. C., *September 15, 1905.*

The meeting was called to order at 10.15 a. m. by the Chairman.

Present: All the members of the Board.

The Secretary read the minutes of the third and fourth meetings.

The Chairman stated that, if there were no objection, the adoption of the minutes would be postponed until the members of the Board had had an opportunity to see them in manuscript form, and then if there were any corrections to be made, it could be done.

There being no objection, the minutes were considered adopted, subject to such correction as might be found necessary.

The Chairman stated that the next business in order was the consideration of communications received; that the Acting Chairman of the Isthmian Canal Commission had prepared data respecting the depths of harbors of the world, sizes of ships in existence and those being constructed, and other relevant matter, and that copies of these data had been given each member.

After a careful consideration of these data, Mr. Parsons offered the following resolution, which was adopted:

Resolved, That the Executive Committee be charged with the work of collecting data concerning the depths existing in the principal commercial ports of the world, and shall submit this information as soon as practicable; also that the information on this subject already received be not placed upon the minutes or printed, but shall be filed with other records.

Mr. Guérard laid before the Board a paper he had prepared containing physical data respecting the existing canals of Europe. (See Appendix D.)

The Chairman stated that he had received a call from Mr. Bunau-Varilla, who wished to place his services at the disposal of the Board, if it cared to utilize them, and who would answer any questions that might be asked him concerning the solution of the canal problem that he had submitted to the President of the United States.

The Chairman also stated that the reason Mr. Bates did not appear before the Board at its last meeting was the fact that he had not received some documentary matter from his printer, and therefore could not make a proper presentation of his project, but that he was ready to appear before the Board at any later session.

It was the sense of the Board that the Chairman communicate with Messrs. Bates and Bunau-Varilla, according the latter the morning (after 10 o'clock) of Tuesday, the 19th of September, and Mr. Bates the afternoon of the same day (after 3 o'clock), for the presentation of their projects.

The Chairman stated that he had received from the President of the United States a paper containing a statement of his views on the canal, which were expressed to the Board in general terms on Monday last, at Sagamore Hill. The paper follows:

REMARKS OF THE PRESIDENT TO THE CONSULTING BOARD OF ENGINEERS OF THE ISTHMIAN CANAL COMMISSION.

SAGAMORE HILL, *September 11, 1905.*

What I am about to say must be considered in the light of suggestion merely, not as direction. I have named you because in my judgment you are especially fit to serve as advisers in planning the greatest engineering work the world has yet seen; and I expect you to advise me, not what you think I want to hear but what you think I ought to hear.

There are two or three considerations which I trust you will steadily keep before your minds in coming to a conclusion as to the proper type of canal. I hope that ultimately it will prove possible to build a sea-level canal. Such a canal would undoubtedly be best in the end, if feasible; and I feel that one of the chief advantages of the Panama route is that ultimately a sea-level canal will be a possibility. But while paying due heed to the ideal perfectibility of the scheme from an engineer's standpoint, remember the need of having a plan which shall provide for the immediate building of a canal on the safest terms and in the shortest possible time. If to build a sea-level canal will but slightly increase the risk, and will take but a little longer than a multilock higher-level canal, then of course it is preferable. But if to adopt the plan of a sea-level canal seems to incur great hazard and to insure indefinite delay, then it is not preferable. If the advantages and disadvantages are closely balanced I expect you to say so. I desire also to know whether, if you recommend a high-level multilock canal, it will be possible after it is completed to turn it into or to substitute for it, in time, a sea-level canal, without interrupting the traffic upon it. Two of the prime considerations to be kept steadily in mind are:

(1) The utmost practicable speed of construction.

(2) Practical certainty that the plan proposed will be feasible; that it can be carried out with the minimum risk.

The quantity of work and the amount of work should be minimized so far as is possible.

There may be good reason why the delay incident to the adoption of a plan for an ideal canal should be incurred; but if there is not, then I hope to see the canal constructed on a system which will bring to the nearest possible date in the future the time when it is practicable to take the first ship across the Isthmus; that is, which will in the shortest time possible secure a Panama waterway between the oceans of such a character as to guarantee permanent and ample communication for the greatest ships of our Navy and for the largest steamers on either the Atlantic or the Pacific. The delay in transit of the vessels owing to additioual locks would be of small consequence when compared with shortening the time for the construction of the canal or diminishing the risks in the construction.

In short, I desire your best judgment on all the various questions to be considered in choosing among the various plans for a comparatively high-level multilock canal, for a lower-level canal with fewer locks, and for a sea-level canal. Finally, I urge upon you the necessity of as great expedition in coming to a decision as is compatible with thoroughness in considering the conditions.

The Chairman laid before the Board a paper from Maj. Cassius E. Gillette, Corps of Engineers, U. S. Army, entitled "The Panama Canal: Some serious objections to the sea-level plan," and stated that the same had already been published in the Engineering News.

The Chairman stated that in compliance with the resolution passed at the third meeting he had addressed letters as follows:

To Mr. Hunter, for information in respect to the Manchester Ship Canal;

To Mr. Tincauzer, for information in respect to the Kiel Canal;

To Mr. Welcker, for information in respect to the North Sea Canal;

To Mr. Quellennec, for information in respect to the Suez Canal and the Corinth Canal; and

To Mr. Ripley, for information in respect to the St. Marys Falls Canal,

four of whom had already submitted papers on these subjects, which papers were now before the Board. (See Appendix D.)

General Abbot presented a paper entitled "Some of the Hydraulic Problems of a Sea-Level Panama Canal." (See Appendix E.)

In accordance with the resolution passed at the third meeting, the Board took under consideration the conditions affecting the construction of dams. Mr. Stearns spoke at length on the subject, illustrating his remarks by drawings.

At 1 p. m. the Board took recess.

At 3 p. m. the full Board reassembled.

The afternoon session was spent in discussing the location and construction of dams, but no definite action was taken on the subject.

The Chairman stated that the Secretary of the Isthmian Canal Commission was making preliminary arrangements for the trip to the Isthmus, and desired to know the personnel of the party.

It was the sense of the Board that the Secretary, two stenographers, the interpreter, and necessary messengers should accompany them to the Isthmus.

On motion, the Board adjourned at 5.50 p. m., to meet to-morrow at 10 a. m.

JOHN C. OAKES,
Captain, General Staff, Secretary.

SIXTH MEETING.

WASHINGTON, D. C., *September 16, 1905.*

The meeting was called to order at 10 a. m. by the Chairman.

Present: The CHAIRMAN, and Messrs. NOBLE, BURR, ABBOT, STEARNS, RIPLEY, RANDOLPH, HUNTER, TINCAUZER, GUÉRARD, QUELLENNEC, and WELCKER.

The Chairman announced that the reading of the minutes of the last meeting would be dispensed with.

The Chairman stated that he had received a letter from the Chairman of the Isthmian Canal Commission inclosing a pamphlet prepared by Mr. Wm. Ham. Hall, of California, entitled "A Statement of the Panama Canal Engineering Conflicts, and a Review of the Panama Canal Projects."

On motion, the document was laid on the reference table.

At this point Mr. Guérard read the following notes as giving his ideas on the proper method of procedure of the Board:

[Translation.]

The Board discussed at great length in its meeting of yesterday the proposition of one of its members tending toward the adoption of a resolution that "a sea-level canal is possible."

This proposition was followed by many remarks.

I also doubted the utility and advisability of such a serious declaration. It appeared to me that the object of our esteemed colleague was to indicate a line of direction for our studies. I stated this, and said that the programme of our work appeared to me clearly defined in the explanation made by the President during our visit at Sagamore Hill on September 11, and repeated in a letter, copies of which were handed to us yesterday.

No action on this matter was taken.

I beg to complete my remarks of yesterday by the following proposition:

I propose that the Board of Consulting Engineers request from the Isthmian Canal Commission a plan for a sea-level canal to serve as a starting point and a basis for its work.

This project should be presented in such a shape as to allow a clear comprehension of the essential points, ascertain distinctly the nature of the works to be executed, determine the quantities, and determine and verify the unit prices and estimates.

It should include, besides the general plans, detail plans of the important works, such as the outlet to the sea—the arrangement of which, as embodied in the old plans, does not escape criticism—the necessary locks, etc.

2. An estimate of the amount of work to be accomplished.

3. A detail estimate, with unit prices applied to each section.

4. A brief explanatory statement.

The Isthmian Canal Commission can all the more readily comply with the wishes of this Board as this project exists, Part III of the document handed to the Consulting Board. But the elements of this project are distributed in the numerous documents given us, and are not presented in a compact form to permit a clear understanding and study of all the details.

With this project before them, the Consulting Board would be able to study, in succession, the different parts, and therefore form their opinion promptly as to the changes that should be made to complete a project that the Board may approve.

After a thorough discussion of the subject, Mr. Hunter proposed the following resolution, which was adopted:

Resolved, (1) That this Board undertake the study of a sea-level plan for the isthmian canal at the earliest possible date.

(2) That a committee composed of the Chairman and three members of the Board to be designated by him shall, with the collaboration of the Isthmian Canal Commission and their staff, prepare at once a project for a sea-level canal.

(3) That the project shall be prepared in outline form and shall be accompanied by a description and by an estimate of cost.

(4) That the project as thus developed shall be used as the basis of the further discussions of the Board in respect to the plans of the canal, with or without locks, which may be finally adopted by the Board.

In accordance with the preceding resolution, the Chairman named Mr. Guérard, Mr. Burr, and Mr. Hunter to serve on the committee.

The Board then took under consideration the subject of dams. After discussion, Mr. Burr presented the following resolution, which was adopted:

Resolved, That the Isthmian Canal Commission be requested to make further borings at the Gatun dam site and to extend topographic surveys with a view to the suitable location of locks and spillways, and in the meantime that Mr. Stearns be requested to proceed with the development of his plans for the Gatun dam.

Mr. Randolph offered the following resolution, which was adopted:

Resolved, That it is desirable that studies shall be made of the practicability of developing a sea-level canal from any project which primarily involves a lock canal.

At 12.10 p. m. the meeting adjourned, to meet at 10 a. m. on Tuesday, September 19.

JOHN C. OAKES,
Captain, General Staff, Secretary.

SEVENTH MEETING.

WASHINGTON, D. C., *September 19, 1905.*

The meeting was called to order at 10 a. m. by the Chairman.

Present: The CHAIRMAN, and Messrs. NOBLE, ABBOT, STEARNS, RIPLEY, RANDOLPH, HUNTER, TINCAUZER, GUÉRARD, QUELLENNEC, and WELCKER.

The Chairman introduced Mr. P. Bunau-Varilla, who spoke at length on the subject of his paper, submitted to the President of the United States, entitled "A Solution of the Problem of Panama." (See Appendix F.)

Toward the close of the morning session the Chairman stated that he had received a communication from the Chairman of the Isthmian Canal Commission, informing him that he had completed arrangements for the trip to the Isthmus, and that the Board and Commission would embark on the steamship *Havana* on the 28th instant.

The Chairman also stated that the next meeting of the Board would be held on September 22, at 10 a. m.

At 1.15 p. m. the Board took recess until 3 p. m.

The Board reassembled at 3 p. m.

Present: The same members as at the morning session.

The Chairman called the meeting to order, and introduced Mr. Lindon W. Bates to the Board.

Mr. Bates then addressed the Board on the subject of his paper, "The Panama Canal System and Projects." (See Appendix G.)

After the departure of Mr. Bates, the Chairman stated that the reading of the minutes had been omitted at the morning session, and that unless there was objection the minutes would be then read.

The minutes of the meeting of September 15 were read and adopted.

The minutes of the meeting of September 16 were then read and adopted.

The Chairman, for the Sea-Level Canal Committee, reported progress, stating that the preliminary steps were being taken by the drafting force in this building in line with the requirements of the resolution. The force at work on the preparation of a sea-level canal plan would be rapidly increased, in order to make better progress.

He further stated, with reference to the requirement that the Commission be requested to give instructions for further borings and surveys at the site of Gatun dam, that on Saturday afternoon the Commission sent to the chief engineer on the Isthmus a telegram directing that he install boring apparatus at once and make certain surveys. This telegram was sufficient to guide him in the work until detailed instructions could reach him by mail on the steamer leaving New York on the 23d. The members of the Board would arrive there two or three days after the letter.

The Chairman then asked Mr. Stearns if he had anything to say about this matter.

Mr. STEARNS. I was called here last Saturday in consultation about the telegram to Panama, and the Chairman of the Board suggested that there might be a better site than that submitted the other day. The site suggested by the Chairman seemed to offer some advantages, and I think that some project can be arranged which will be more advantageous than the one I proposed. A plan is being prepared to indicate where the borings should be taken.

The question of the subject for discussion at the next session was then taken up.

The subject of the Gamboa dam was proposed by Mr. Hunter, who suggested first a study of the most desirable site, and, second, the manner of constructing the dam. He considered it a question of vital importance, and one that would not be much assisted by an examination of the site.

The Chairman stated for the information of the Board that he had been told by General Hains, one of the members of the Commission, that he was having prepared, and had about completed, a plan of a dam at Gamboa, with estimates of amounts of materials according to the usual formula for the construction of dams.

It was decided that the subject of dams should be the subject for the next meeting.

The Chairman then read a letter from Joshua A. Hatfield, president of the American Bridge Company, of New York, extending an invitation to the Board of Consulting Engineers and the Isthmian Canal Commission to inspect the large working models which have been installed at Bound Brook, N. J., of the Dutton pneumatic lock and dam regulation device.

No action was taken upon this invitation.

The meeting thereupon adjourned until Friday morning, September 22, 1905, at 10 o'clock a. m.

JOHN C. OAKES,
Captain, General Staff, Secretary.

EIGHTH MEETING.

WASHINGTON, D. C., *September 23, 1905.*

The meeting was called to order at 10 a. m. by the Chairman.

Present: All the members of the Board.

The minutes of the preceding meeting were read, corrected, and adopted.

The Chairman stated, on behalf of the committee that was requested to collect data respecting the depths of great harbors of the world, sizes of steamships engaged in commerce and of naval vessels, that he would report progress as follows:

A communication had been sent to the Superintendent of the Coast and Geodetic Survey, in this city, in substance as follows:

The Board of Consulting Engineers for the Panama Canal is desirous of having authentic official information as to the depth available for navigation in the 50 principal commercial and naval harbors of the world. These data will be best expressed by the depth of the bar or entrance at mean low water, and at high water at lowest neap tide, thus enabling a mariner to know on what he can count on arrival. The latest information will be appreciated.

A letter similar to the above had also been sent to the Hydrographer of the Navy Department, who had notified one of the members of the committee that he would be very glad to facilitate the collection of such data in every way in his power. A similar letter, relating only to harbors of the United States, had been addressed to the Chief of Engineers, U. S. Army, and he had also given verbal assurance of his willingness to furnish the data required.

The Chairman further stated, on behalf of the special committee appointed to prepare a plan for a sea-level canal, which committee was created under a resolution adopted at the last meeting, that he had been assured of the collaboration of the members of the Isthmian Canal Commission in this respect, and that he had made arrangements that the draftsmen in the office of the Commission, together with others to be employed, should press the work to completion. A map suitable for illustrating the alignment for a sea-level canal fortunately was at hand on the wall of the Board room, reduced to 1:20000 from 1:5000. It is a map about 10 feet long, and on it is shown all topography that is on the larger map. It was being copied and would soon be finished. The draftsmen had instructions to continue their work of preparing profiles and cross sections.

About six months ago, by direction of the Isthmian Canal Commission, computations were begun for a sea-level canal, and those calculations had been completed. Mr. Harden, the chief draftsman, used, where available, the data collected by the Isthmian Canal Commission of 1901. They were based upon cross sections which he had been instructed to use, but which probably would not be entirely acceptable to the Board. The cross sections assumed have a bottom width of 150 feet and a depth of 35 feet, slopes of 1 on 1, and superior slopes somewhat flattened, without any berm. These computations gave 229,000,000 cubic yards of excavation.

Under the instruction of the Commission, some six to ten months ago, topographic work was inaugurated on the Isthmus for the purpose of securing an entire resurvey of all the topography from ocean to ocean. The work was begun at Culebra and was under the direction of Mr. W. B. Ruggles, topographer. Up to the time when the last reports of his work were received, he had completed the survey of the section from Obispo to Paraiso, a length of 7½ miles. In that portion of the work where the slopes are changeable, his cross sections were taken at very close intervals; in those portions where the grade is nearly uniform and the topography unmarked by notable features, the cross sections were considerably farther apart. The quantity to be excavated had also been computed in that section and was based upon a cross section of 150 feet bottom width, depth of water 40 feet, and berms 50 feet on each side of the canal, and dry slopes of 1 on 1. The total amount to be excavated could not be given at the time, but the data were in the office and available for use, and the chief draftsman assured the Board that when it should be ready to embark on its visit to the Isthmus he would have those two maps ready, and also the computations of the excavation on the whole line and on the whole line as modified by the interpolation of the data collected by Mr. Ruggles, so that that would then be ready for preliminary discussion. Mr. Harden had not, however, computed or made any attempt to compute the excavation due to the diversion channels, a matter which the special committee would give attention to, but it must be quite evident to all that to collect data in regard to these diversion channels would involve first accurate maps to be obtained only by surveys, which would require considerable time.

The Board discussed the coming trip to the Isthmus and decided to take such documents and data as would likely be needed. It was also the sense of the Board that three stenographers, instead of two, should accompany them, and that at least two draftsmen should be included in the force of clerks.

The Board then took under consideration the invitation of Mr. Stearns to visit the Wachusett reservoir. Mr. Randolph offered the following resolution, which was adopted:

Resolved, That this Board visit the Wachusett reservoir at Clinton, Mass., for the purpose of inspecting the dams and other hydraulic works, on Wednesday, September 27, and that the fact of our intention to visit this place be communicated to the Isthmian Canal Commission with an invitation, on behalf of this Board, to accompany us.

The Chairman stated that the cablegram which was sent to the chief engineer relating to the making of certain borings and surveys at Gatun, had been followed by a letter sent to the Chairman of the Commission, together with a memorandum and map prepared by Mr. Stearns, showing the general scheme for a dam at Gatun, with indications in this memorandum as to where further surveys and borings were to be made. That letter would go to Panama on the steamer sailing the next day. It would reach Panama in due time in about seven days. The boat on which the Board would take passage would make the trip in five days, so the letter would be only about two days ahead of the Board.

Mr. Stearns then spoke at length on the subject of dams, their location and construction.

At 1 p. m. the Board took recess.

The Board reassembled at 3 p. m., all members being present except Mr. Quellennec.

The Chairman stated that he had received from the Isthmian Canal Commission a copy of two original sheets showing the recent hydrographic survey of Limon Bay by the U. S. Coast and Geodetic Survey. The data, in very great detail, are shown on two sheets of considerable size.

Another sheet, made about a year ago, which was procured from the Commission, shows soundings in mud to rock or hard material. The data respecting that bay are quite complete.

It had been found, during recess, that a report was made by Mr. Dose and forwarded to the Commission by the chief engineer, showing the results of borings on the axis of the canal all the way from kilometer 20 to kilometer 60, at intervals of 1 kilometer; these were carried to a depth of −40; and the borings that had been conducted since had been for the purpose of showing depth to rock at intervals of 500 feet between these kilometer borings. The data at kilometer intervals were nearly complete. At the time the report was made three or four holes had not reached the proposed limit of penetration, i. e. −40, but had since.

A telegram had been sent to the chief engineer, requesting him to have prepared, before the arrival of the Board on the Isthmus, a report, with samples of the material penetrated, showing the results of these borings, especially from Obispo to Paraiso. The Board might expect to find on arrival very complete information concerning the strata and their constitution throughout the whole of the deep cut.

Another fact mentioned was that a member of the Commission had prepared from the records of the Panama Railroad Company a map showing the high-water mark, as referred to the profile of the railroad line, for all of the important floods that occurred and which caused damage to the railroad from 1879 to 1890. The data were not great in amount, but were important as showing the water elevation with date as referred to the railroad track—all derived from reports written at the dates of the floods.

Mr. Stearns stated that it was desirable to have borings on a line from Sosa Hill to the mainland.

The Chairman stated that he would amend the telegram about to be sent so as to include the request for borings on the site of the suggested dam from Sosa Hill across to the mainland at Panama.

The meeting adjourned at 4 p. m., to meet at the Wachusett reservoir, Clinton, Mass., on Wednesday, September 27, at 11 a. m.

JOHN C. OAKES,
Captain, General Staff, Secretary.

NINTH MEETING.

CLINTON, MASS, *September 27, 1905.*

The Board assembled at the Wachusett reservoir, Clinton, Mass., at 11 o'clock.

Present: The CHAIRMAN, and Messrs. NOBLE, ABBOT, STEARNS, RIPLEY, RANDOLPH, HUNTER, GUÉRARD, QUELLENNEC, TINCAUZER, and WELCKER.

An inspection of the various features of the reservoir and its controlling devices was made

by the Board. Particular attention was given the earthen dike. A lecture with maps and lantern slides was given by the chief engineer of the work, Mr. Stearns, a member of the Board.

The meeting was adjourned to assemble at 10 a. m., September 30, on board the S. S. *Havana*, leaving New York, N. Y., on the afternoon of September 28.

JOHN C. OAKES,
Captain, General Staff, Secretary.

TENTH MEETING.

S. S. HAVANA, AT SEA, *September 30, 1905.*

The meeting was called to order at 10 o'clock by the Chairman.

Present: The CHAIRMAN, and Messrs. PARSONS, BURR, ABBOT, STEARNS, RIPLEY, RANDOLPH, HUNTER, TINCAUZER, GUÉRARD, QUELLENNEC, and WELCKER.

The Secretary read the minutes of the eighth and ninth meetings, which were adopted.

The Chairman called attention to the hospitality and courtesies extended to the Board by Mr. Tuttle, the president of the Boston and Maine Railroad, and also by the Metropolitan Water and Sewerage Board of Massachusetts, in connection with the visit of the Board to the Wachusett reservoir on the 27th instant, and suggested that the Board make formal acknowledgment for same.

Mr. Randolph offered the following resolutions, which were unanimously adopted:

Resolved, That the thanks of this Board be, and that they are hereby, tendered to the president of the Boston and Maine Railroad, Mr. Lucius Tuttle, for the use of a special train and private car placed at the disposal of the Board for use in visiting the Wachusett dam. The civilities extended by the officials of the railroad company were greatly appreciated.

Be it further resolved, That the thanks of this Board be, and that they are hereby, tendered to the Metropolitan Water and Sewerage Board of Massachusetts for the courtesies and hospitality extended to this Board on the 27th instant, when under their auspices the Wachusett dam and north dike were visited—a visit full of suggestion and enjoyment to those who participated in it.

The Board took under consideration the report of the hearing given Mr. Bates on the 19th instant, and it was the sense of the Board that before making the report of this hearing a part of the record in the minutes of the Board, the Secretary should forward a copy to Mr. Bates by the first mail leaving Panama after the arrival of the Board, for his revision.

Mr. Parsons offered the following resolution, which was adopted:

Whereas Mr. Bates in his pamphlet has discussed the details of various estimates prepared by other authorities, but gives for his own projects only total lump sums: Therefore

Resolved, That in order to permit a proper comparison of Mr. Bates's projects to be made with other projects, he be requested to append to his oral discussion answers to the following questions:

"1. What are the quantities of materials in the main component parts of your projects which formed the basis of your estimate?

"2. What are the unit prices to be applied to such quantities to make the lump-sum estimates contained in your pamphlet?"

The Chairman stated that he had received in Washington, just prior to departure therefrom, a letter from the Hydrographer of the Navy Department, responding to a communication addressed to him on behalf of the Board asking for water depths in the great harbors of the world. The data which he furnished had been copied and were before the Board, and would subsequently appear in the appendix material (see Appendix H). Reply had not been received from the Superintendent of the Coast and Geodetic Survey, nor from the Chief of Engineers of the Army, but responses would no doubt be received later.

The Chairman further stated, on behalf of the committee appointed by the Board to prepare a plan for a sea-level canal, that the draftsmen were at work carrying out the instructions of this special committee, preparing profiles or cross sections of the canal line to illustrate the estimates of quantities which had been and were being prepared, all of which would be submitted. Some estimates of those quantities had already been stated to the Board. Further data would soon be ready respecting a sea-level canal; but it would take a good deal of time to collect any complete

data—at least several days longer. The definite quantity of rock and other material to be excavated could not be known until arrival on the Isthmus and the receipt of the report of the chief engineer showing the results of the completed borings along the canal line.

The Board then discussed tidal variations as affecting the various canals of the world and other relevant subjects, no action being taken thereon.

At 12.30 p. m. the Board adjourned, to meet Monday, October 2, at 10 a. m.

JOHN C. OAKES,
Captain, General Staff, Secretary.

ELEVENTH MEETING.

S. S. HAVANA, AT SEA, *October 2, 1905.*

The meeting was called to order at 10 a. m. by the Chairman.

Present: The CHAIRMAN, and Messrs. PARSONS, BURR, ABBOT, STEARNS, RIPLEY, RANDOLPH, HUNTER, TINCAUZER, GUÉRARD, QUELLENNEC, and WELCKER.

The Secretary read the minutes of the ninth and tenth meetings, which were adopted.

The Chairman laid before the Board a letter he had received the day after the Board adjourned in Washington from Mr. C. D. Ward, a member of the American Society of Civil Engineers, inclosing a copy of his paper on "The Gatun Dam," which was read before the American Society of Civil Engineers on May 18, 1904, and asking that his plan be given due consideration.

On motion of Mr. Parsons it was directed that Mr. Ward's paper be printed in the appendix. (See Appendix I.)

On behalf of the committee appointed to prepare a plan for a sea-level canal, the Chairman reported progress, and stated that the work would be completed in a very short time.

The Chairman stated that the Isthmian Canal Commission caused to be made plans and computations of a dam at Gamboa with its crest raised to a height of +200. The drawing on which these computations were based was at hand, and the chief draftsman had given the quantities for a masonry dam carried to rock, including in his computation all work necessary to close the gaps in the hills adjacent on either shore or bank, but not including the spillway. He estimated for a dam of typical profile the total quantity of 879,000 cubic yards of concrete masonry. The committee had had computations made to show what the quantities would be in a similar dam if reduced to a height of 150 feet. The quantities for the latter dam were about 370,000 cubic yards. That presupposes the diminution of the original quantities by a reduction of 50 feet from the height of the dam (using the same profile) taken from the bottom. The draftsman was also computing quantities for a dam of 150 feet (using same profile), the diminution being effected by cutting off 50 feet from the top of the dam as planned. This computation will be completed to-day.

The Board discussed the formation of the strata underlying the proposed dams.

Mr. QUELLENNEC. I think it would be impossible by borings to determine at what depth the underlying material is suitable for a foundation; that it would be necessary to uncover the strata before determining the question. I visited the Assuan dam during construction and this difficulty was experienced there. The English engineers had considered a certain depth as proper for the foundations, but on uncovering the strata it was found necessary to deepen the level from 6 to 8 meters (20 to 26 ft.), the surface rock being poorly adapted for foundations, although it is a granite of first quality showing clearly above the water level at the time of low water of the Nile.

Mr. STEARNS. Mr. Chairman, my experience has been similar. In the construction of the Wachusett dam we made borings with diamond drills and got all the information we could. We then considered the matter as thoroughly as possible and concluded that if we allowed an average depth of rock excavation of 15 feet it would be sufficient. As a matter of fact, we went to variable depths. On one hillside was granite and on the other schist, and while the latter was very much

softer it was not necessary to go into it to as great depth, although in places we went probably 15 or 20 feet, and in addition excavated a cut-off trench that went 15 feet deeper; but on the whole, in the schist, I think we did average more than 10 feet. In the granite we went down in two places 45 feet before finding material that was suitable for the foundation. This rock was either rotten or had seams in it so that it was desirable to take it out. When we reached the part where the spillway was located, the height of masonry was so small that we excavated very little, so that, on the whole, the estimate of 15 feet was to a slight extent an overestimate; but taking the main dam alone, 15 feet would have been none too much to allow.

Mr. QUELLENNEC. I do not remember the additional expense involved in the deepening of the Assuan foundations, but it was very great. The material to which I referred was a hard rock of old formation.

The CHAIRMAN. You will find, gentlemen, that the material we have to deal with at Gamboa is of very uniform character, not a very hard material, but there is very little tilting and very little disturbance of the masses; no dikes, no faults or other characteristics which you find in the older rock. You will find in the geological notes of Messrs. Bertrand and Zürcher much information concerning the geology of the Isthmus; it is very well summarized in that paper. (See Appendix B.)

Mr. BURR. I may state, in connection with the studies that are being made for the Gamboa dam, that it is quite possible to design a partial masonry dam, and one study will be of that type, in which the foundation pressures are of considerably less importance than with an all masonry dam.

The CHAIRMAN. The remark that Mr. Quellennec made in regard to the dam at Gamboa will apply, of course, to a dam at Alhajuela. I think the barrage at Assiut raises the water about 40 feet and is founded on sand.

Mr. QUELLENNEC. Yes, with a large concrete apron; but that is a relatively small barrage; it is a barrage for the control of the river to allow the introduction of water into irrigation canals.

The CHAIRMAN. It has a maximum head against it of something like 40 feet.

Mr. QUELLENNEC. Yes.

The CHAIRMAN. Do you know the type of construction of the Assuan dam?

Mr. QUELLENNEC. It is equipped with sluices of the Stoney system. They are now having some difficulty owing to impact of the water falling on the rock in front of the dam. They are now making very great repairs to prevent this damage. I was always in favor of the project of the dam as executed, because the Nile is a river which rises slowly and gives warning beforehand. The river carries no débris, neither sand, stone, nor wood, because between the Assuan dam and the first affluent is a distance of 2,000 kilometers (1,243 mi.); the water of the Nile carries nothing excepting a certain quantity of very light mud. In such a river it is possible to use this system, but in another river which brings down trees, stones, etc., it is not a good system.

The Chairman presented to the Board an itinerary of inspection on the Isthmus, which was approved.

At 11.40 o'clock the Board adjourned, to meet to-morrow at 10 a. m.

JOHN C. OAKES,
Captain, General Staff, Secretary.

TWELFTH MEETING.

S. S. HAVANA, AT SEA, *October 3, 1905.*

The meeting was called to order at 10 a. m. by the Chairman.

Present: The CHAIRMAN, and Messrs. PARSONS, BURR, ABBOT, STEARNS, RIPLEY, RANDOLPH, HUNTER, TINCAUZER, GUÉRARD, QUELLENNEC, and WELCKER.

The reading of the minutes of the preceding meeting was postponed until later in the session.

The Chairman stated that the committee appointed to prepare a plan for a sea-level canal was continuing its studies and developing the same in the form of drawings, but was not yet ready to submit its report.

The advisability of securing certain data from the Isthmian Canal Commission was discussed, the Chairman presenting the following resolution, which was adopted:

Resolved, That the Isthmian Canal Commission be informed that the Board of Consulting Engineers desires that the chief engineer of the Panama Canal be prepared to furnish as much information as is possible respecting the work of excavation so far completed since the assumption of control by the United States, and further information on the following suppositious basis:

Let it be assumed that the total mass to be excavated throughout the whole canal may reach 200,000,000 cubic yards and that half of this quantity will be found between Obispo and Pedro Miguel—what would the chief engineer estimate as a practicable yearly output between the points last named, and what period of time would be required to install a plant adequate for the removal of the yearly output?

As the cost of excavation in time and money would probably be less for the upper masses than for those nearer the level of the sea, it would be desirable that there should be a discrimination in the figures submitted for cost of excavation above level 90 and below the same as applied to (a) hard rock, (b) soft rock, (c) earth.

The Secretary read the minutes of the eleventh meeting, which were adopted.

The Board discussed the question of a lock site near Panama, but no action was taken.

The meeting adjourned at 12.15 p. m., subject to the call of the Chairman.

JOHN C. OAKES,
Captain, General Staff, Secretary.

THIRTEENTH MEETING.

S. S. HAVANA, COLON, PANAMA, *October 10, 1905.*

The meeting was called to order at 9 a. m. by the Chairman.

Present: The CHAIRMAN, and Messrs. PARSONS, BURR, ABBOT, STEARNS, RIPLEY, RANDOLPH, HUNTER, TINCAUZER, GUÉRARD, QUELLENNEC, and WELCKER.

The Secretary read the minutes of the twelfth meeting, which were adopted.

The Chairman asked what the wishes of the Board were respecting a record of the transactions since arriving upon the Isthmus, and it was the sense of the Board that a daily journal should be made and embodied in the minutes.

The Chairman stated that since the last meeting a number of maps and plans had been submitted to the Board, and also a copy of a report by one of the subordinate engineers giving very comprehensive data in regard to several localities, copies of which would be prepared and given to each member; also blueprints and map of Gamboa and profile showing line of borings along the same territory; blueprints made by Mr. Carpenter, assistant engineer; Gatuncillo channel and profile of same; upper Chagres River, and profile of the Atlantic and Pacific tunnel spillways.

At 9.35 o'clock Mr. Stevens appeared before the Board, in accordance with the request made at the preceding meeting. (See Appendix J.)

Messrs. Harrod and Ernst were present at the morning session.

At 11.40 o'clock Mr. Maltby appeared before the Board. (See Appendix J.)

The Board took recess at 1 o'clock.

At 2.15 o'clock the entire Board reassembled, General Ernst also being present.

Mr. Dose appeared before the Board. (See Appendix J.)

At 3.30 o'clock Mr. Bertoncini entered. (See Appendix J.)

The meeting adjourned at 5.15 o'clock, to meet Thursday, October 12, at 9 a. m.

JOHN C. OAKES,
Captain, General Staff, Secretary.

FOURTEENTH MEETING.

S. S. HAVANA, AT SEA, *October 12, 1905.*

The meeting was called to order at 9 a. m. by the Chairman.

Present: The CHAIRMAN, and Messrs. PARSONS, BURR, ABBOT, STEARNS, RIPLEY, RANDOLPH, HUNTER, TINCAUZER, GUÉRARD, QUELLENNEC, and WELCKER.

The reading of the minutes of the thirteenth meeting was dispensed with.

The Board directed that the record of its work on the Isthmus be entered in the minutes; it is as follows:

Wednesday, October 4. Arrived at Colon in the morning. The entire party took train at 9 a. m. and passed over the road to Emperador, where they changed to a construction train and passed through the Culebra cut to Pedro Miguel, again joining the main railroad and proceeding to Panama, thence to La Boca; going on board a sea-going tug, a trip was taken through the canal to the harbor, around the islands of Naos, Flamenco, and Perico, thence returning to the dock, where the party boarded a small launch and proceeded up the canal as far as it was possible to go, returning and taking train for Colon, where they arrived about 7 p. m.

Thursday, October 5. The members of the Board took train at 8 a. m., proceeded to Mindi, where they disembarked and climbed the hills to the eastward of the canal overlooking the country, and examined possible sites for locks and dams. Returned to the train and proceeded to Gatun, where the hills in that vicinity were climbed and a view of the country obtained. The proposed lock and dam sites were inspected, as were also the materials obtained from a series of borings made on the line of the proposed dam; again returned to train and proceeded to Bohio, crossed the Chagres in canoes, and inspected the old lock site of the French company; part of the Board again entered canoes and proceeded down the Chagres River and canal to Gatun, near which place they were met by the rest of the party who had gone to Gatun on train and boarded a launch at that point. The whole party made an inspection of the Chagres and the diversion channels thereabouts, saw the boring operations in progress, returning to Colon at 5 p. m.

Friday, October 6. The whole party except Mr. Tincauzer left the ship at 8 a. m. and proceeded to Bas Obispo, inspecting at that point the possible lock site, thence proceeded to the site of the Gamboa dam, the trace of which was followed throughout its whole extent, as well as the course of the spillway and diversions. The party then returned to Cristobal where the engineering office was visited and all recent maps were consulted. Boarding a tug the party proceeded up the canal as far as possible on account of depth of water, and returning sailed around Limon Bay, noting the various points of interest. The party returned to the ship at 5 p. m.

Saturday, October 7. The party leaving the ship at 8 a. m. proceeded by train to Emperador where they disembarked and climbed the hill at that point overlooking the line of the canal. The office at Emperador was visited and the results of the borings along the line of the canal were examined. Boarding a construction train the party passed through the deepest part of the great cut from Emperador to San Pedro Miguel, visiting all of the dumps and different terraces and observing the working of the steam shovels. Returned to the ship at 7 p. m.

Monday, October 9. The party left the ship at 8 a. m., proceeded to Panama, and drove to La Boca by way of the Ancon Hill. The saddle between the Ancon and Sosa hills was inspected, the boring apparatus observed, and the country studied with a view of a possible construction of tidal locks and dams at this point. Returning to Panama the Board breakfasted with the governor of the Canal Zone, after which an official call was made to the President of the Panama Republic. The office of the Canal Commission was then visited for an inspection of the maps and drawings at that place, after which the party returned to the ship, arriving at 6 p. m.

Wednesday, October 11. Messrs. Stearns, Ripley, Randolph, Parsons, and Burr proceeded by train to Culebra, where the three members first named made a further examination of the western portion of the Culebra excavation. Messrs. Parsons and Burr continued on to Panama for some further matters of inquiry respecting the work of the Board. All returned to Colon at 4 o'clock. Messrs. Davis, Abbot, and Quellennec, accompanied by General Ernst, went by train to Gatun, thence by launch to the mouth of the Chagres River, thence by sea to Limon Bay, skirting the west and south shores of the bay to the mouth of the Mindi, entering the same, proceeded through the canal to Gatun and, returning over the same route, passed out again into the bay and returned to the ship.

The weather during the first five days of the stay of the Board on the Isthmus was exceptionally pleasant, thus facilitating the excursions that have been recorded. On Monday it commenced to rain and the rains continued remittingly but in large volume until the Board left the Isthmus on Wednesday evening. The Board thus had an opportunity to observe the country under favorable conditions, and also when the flow of the rivers was very much increased by the heavy rainfall.

The Chairman stated that after consultation with several members of the Board he had thought it expedient to request that the Chairman of the Isthmian Canal Commission detail Mr. Bertoncini for attendance upon this Board, here and in Washington, and that the request had been complied with. Mr. Bertoncini brought with him extensive data from the archives

of the office of the Commission at Panama, and his knowledge of the canal projects and experience as a computer and draftsman should be of value to the Board.

The Chairman further stated that the Sea-Level Canal Committee had no progress to report, inasmuch as they had been occupied continuously during the past week, but that it would at once actively resume its duties and results might be expected in a short time.

The Board took under consideration the determination of the size of the tidal locks, and the following resolution was adopted:

Resolved, That it is the sense of this Board that the tidal locks at the Pacific end of the canal shall have an available width of 100 feet and an available length of 1,000 feet.

Mr. Stearns offered the following resolution, which was adopted:

Resolved, That a committee composed of the Chairman and three members of the Board to be appointed by the Chairman shall prepare plans for a lock canal; that the project shall be prepared in outline form and shall be accompanied by a description and an estimate of cost.

Each member of the Board was presented with a profile drawing of the Panama Canal and a sheet showing the total amount of excavation for the canal line between Colon and Naos Island at different levels and with different cross sections. These documents were prepared by Mr. Bertoncini, by direction of Mr. Wallace, and were used by the latter as a basis for the computation of quantities in his report.

Mr. Parsons offered the following resolution, which was adopted:

Resolved, That a committee of four, of which the Chairman shall be one, shall be appointed by the Chairman to prepare a series of arbitrary unit prices for the various component parts of the canal construction, and that said prices shall be used by the committees on preparation of plans for canals at sea level and with locks.

The Chairman announced the following appointments:

Lock-Canal Committee: Messrs. Stearns, Tincauzer, and Ripley.

Unit-Prices Committee: Messrs. Parsons, Welcker, and Randolph.

At 11 a. m. the Board adjourned, subject to the call of the Chairman.

JOHN C. OAKES,
Captain, General Staff, Secretary.

FIFTEENTH MEETING.

S. S. HAVANA, AT SEA, *October 16, 1905.*

The meeting was called to order at 9 o'clock by the Chairman.

Present: The CHAIRMAN, and Messrs. PARSONS, BURR, ABBOT, STEARNS, RIPLEY, RANDOLPH, HUNTER, TINCAUZER, GUÉRARD, QUELLENNEC, and WELCKER.

The Secretary read the minutes of the thirteenth and fourteenth meetings, which were adopted.

The Chairman, on behalf of the Sea Level and Lock Canal Committees, stated that computations were being made, sketches were being prepared, and studies were being pressed.

The Secretary stated that if the resolution of the Board to meet in New York after the first meeting in Washington was adhered to, it would necessitate considerable labor in the way of preparations, etc., and he would like instructions.

Mr. Guérard said that the documents in Washington would be daily required; to transfer the Board from Washington to New York would occasion considerable delay compared with the short time remaining for studies. His mission should not last more than two or three months. It was necessary therefore that it should end on November 30 at the latest. Consequently there was no time to lose. If the Board should have to make a project, as there appeared to be none existing, and the duration of the work of the Board should therefore have to be increased, Mr. Guérard, the nature of his mission being clearly limited and whose duties and business did not permit him to remain absent indefinitely, would in that case be under obligation to take special steps and probably consult his Government.

After discussion, Mr. Randolph moved that the Board reconsider the action relating to future meetings, taken during the first meeting of the Board, in so far as that action referred to meetings in New York.

A vote was taken—7 members voting aye and 4 voting no. The Chairman thereupon announced the annulment of that part of the resolution which related to future meetings to be held in New York.

Mr. Welcker, on behalf of the foreign members of the Board, stated that they wished to complete their work so that they might return to Europe on or about the 28th of November.

At 11 a. m. the Board adjourned, to meet at Washington, D. C., on Friday, October 20, at 9.30 a. m.

JOHN C. OAKES,
Captain, General Staff, Secretary.

SIXTEENTH MEETING.

WASHINGTON, D. C., *October 20, 1905.*

The meeting was called to order at 9.35 a. m.

Present: The CHAIRMAN, and Messrs. NOBLE, PARSONS, BURR, ABBOT, RIPLEY, RANDOLPH, HUNTER, TINCAUZER, GUÉRARD, and WELCKER. Mr. STEARNS entered the meeting at 10 o'clock.

The Secretary read the minutes of the fifteenth meeting, which were adopted.

With respect to the date of expected completion of the work of the Board, it was the sense of all the members present that this should be arranged if possible so as to meet the wishes of those members who have other engagements and responsibilities; that every effort should be made to reach a conclusion so that a final adjournment could be taken by the end of November, thus permitting the European members to make arrangements for return steamer passages.

The Chairman stated, in referring to routine business, that the three special committees were making rapid progress.

He had seen the Secretary of War, whose engagements were such that it would be convenient for him to receive an official call from the Board some day during the next week, the day not being important. The Chairman recounted to the Secretary the progress attained by the Board, and the latter was much pleased with the statement. No desire was indicated on his part, or that of the President, respecting the deliberations of the Board or the time when it should make its report, thus leaving the Board entirely free to carry out its duties.

With respect to communications received, the Chairman announced that he had received from the Superintendent of the Coast and Geodetic Survey a list of harbor depths, and another statement of similar nature from General Mackenzie, Chief of Engineers, U. S. Army, both of which would be printed at an early date and distributed. There had also been received a communication from Mr. Lindon W. Bates, to whom a report of his remarks before the Board had been sent for revision, saying that he was attending to the matter and that his assistants were making calculations as per the request of the Board that he furnish estimate of unit prices and quantities to accompany his project. He would submit reply on the 24th instant.

At 10 o'clock, Mr. Dauchy, one of the engineers of the Panama Canal, appeared before the Board. (See Appendix J.)

At 12.10 p. m. Mr. Dauchy was excused to appear again before the Board at 2.30 o'clock.

The Chairman requested instructions from the Board respecting a hearing for Mr. Wallace, formerly chief engineer of the Isthmian Canal.

It being the sense of the Board that Mr. Wallace should be requested to appear before it, the Chairman announced that he would endeavor to make an appointment for an early date.

Mr. Burr offered the following resolution:

Resolved, That this Board adopt for the minimum lock sections for the lock plan canal a usable width of 95 feet, a usable length of 900 feet, and a minimum depth of 40 feet over miter sills.

At the request of one of the members, action on this motion was deferred until the afternoon session.

The Board took recess at 12.40 p. m.

The Board reassembled at 2.30 p. m.

Present: The CHAIRMAN, and Messrs. NOBLE, PARSONS, BURR, ABBOT, STEARNS, RIPLEY, RANDOLPH, HUNTER, TINCAUZER, GUÉRARD, WELCKER, and Mr. Dauchy.

The Chairman proceeded with the questioning of Mr. Dauchy. (See Appendix J.)

Mr. Dauchy was excused from attendance on the Board at 3.15 p. m.

The unfinished business was then taken up, and a discussion ensued relative to the motion introduced at the morning session by Mr. Burr respecting the minimum dimensions of locks. It was decided that inasmuch as the Lock-Canal Committee would probably be able to report on this matter at the next meeting, it would be unnecessary to take up the matter at this time, and, on motion of Mr. Randolph, Mr. Burr's motion was laid on the table.

Mr. Stearns thereupon offered the following resolution, which was adopted:

Resolved, That the Committees on Sea-Level and Lock Canals be increased by the addition of two members each, to be appointed by the Chairman of the Board.

The Chairman thereupon appointed to the Sea-Level Canal Committee, Messrs. Parsons and Quellennec, and to the Lock-Canal Committee, Mr. Noble and General Abbot.

The chief draftsman was interviewed as to the capacity of his office, and, upon his reporting, it was decided that measures should be taken immediately to obtain additional draftsmen.

The meeting adjourned at 4.20 p. m., to meet on Friday, October 27, at 9.30 a. m.

JOHN C. OAKES,
Captain, General Staff, Secretary.

SEVENTEENTH MEETING.

WASHINGTON, D. C., *October 27, 1905.*

The meeting was called to order at 9.50 a. m.

Present: The CHAIRMAN, and Messrs. NOBLE, PARSONS, BURR, ABBOT, STEARNS, RIPLEY, RANDOLPH, HUNTER, TINCAUZER, GUÉRARD, QUELLENNEC, and WELCKER.

The Secretary read the minutes of the sixteenth meeting, which were adopted.

The Secretary stated that the following communications had been received: From Mr. Maltby, respecting tidal data at the Panama Railroad pier (see Appendix J), and from Mr. Parsons, respecting unit prices, copies of which had been distributed. Also a letter from the chief engineer, Mr. Stevens, to General Davis, inclosing a summary of excavation and costs at Culebra for the months of July, 1904, to September, 1905 (see Appendix K), and the complete report for the month of September. Copies of the summary had been distributed. Reply had also been received to the cablegram sent to the chief engineer respecting borings at the Ancon-Sosa saddle, stating that the majority of the data asked for was on the *Finance* and the balance would follow on the next ship. There had also been received from Mr. A. B. Nichols blueprints of maps of the slide in Culebra cut between kilometers 55 and 56, which were asked for by Messrs. Stearns, Randolph, and Ripley. Copies of a report by Mr. Guérard upon the jetties at Colon had been prepared and, as soon as the drawings were inserted, would be distributed. Also a communication from General Hains respecting estimates in the report of the chief engineer of February 1, 1905. The revised report of Mr. Bates's hearing had been received and was being printed.

The Chairman stated that he had seen the Secretary of War, and had obtained from him an order on the Chief of Staff of the Army for the detail of some draftsmen for work with the Board. Six men of experience had reported, who were competent to do almost anything in drafting work, and the force would be adequate.

The Chairman further stated that he had addressed a letter to Mr. John F. Wallace, the late chief engineer of the Panama Canal, expressing to him the wishes of the Board that he appear

for examination. He had responded to this request, stating that he would willingly appear before the Board at any agreeable date, and place such knowledge as he might possess at its service. The Chairman also said that Mr. Wallace was in the city, and requested the instructions of the Board respecting a hearing.

It was the sense of the Board that Mr. Wallace be requested to appear before it that afternoon at 3 o'clock, and that he be accorded another hearing on November 3, in order that he might prepare in writing any answers to questions to which it would be impossible to answer offhand at the first hearing.

The question of unit prices was discussed, but no action taken.

The subject of locks was discussed at length. In this connection General Abbot offered the following resolution, which was adopted:

Resolved, That the Board adopt for the size of locks the following usable dimensions, viz, depth 40 feet, width 100 feet, and length 1,000 feet, and that they be provided with intermediate gates when such be necessary to save water.

The Board took recess at 11.40 a. m. for the purpose of waiting upon the Secretary of War.

At 2.30 p. m. the entire Board reassembled.

The Chairman stated that the Sea-Level Canal Committee had for illustration a map showing in general outline the plans that they had been studying, and on which their computation of quantities was based.

Mr. Hunter being familiar with it in all its details described the scheme as outlined by this map. Professor Burr described to the Board the proposed Gamboa dam, and Mr. Parsons described the proposed method of treating the waters of the streams which intersect the line of canal.

Mr. Wallace appeared before the Board, and after a formal introduction and a short statement he was excused to reappear for a more extended hearing on November 3, at 10 a. m. (See Appendix J.)

At 5.10 p. m. the Board adjourned, to meet at 10 a. m. on Saturday, October 28.

JOHN C. OAKES,
Captain, General Staff, Secretary.

EIGHTEENTH MEETING.

WASHINGTON, D. C., *October 28, 1905.*

The meeting was called to order at 10.10 a. m.

Present: The CHAIRMAN, and Messrs. NOBLE, PARSONS, BURR, ABBOT, RIPLEY, RANDOLPH, HUNTER, TINCAUZER, GUÉRARD, QUELLENNEC, and WELCKER.

The reading of the minutes of the seventeenth meeting was dispensed with.

The Chairman stated that he had the official reports of the Government on the Delaware breakwater, harbor of Delaware Bay, and also of the San Pedro jetty, on the coast of California, which is subjected to physical conditions analogous to those which the Colon jetties would encounter. Data concerning five or six other extensive jetties which have been built by the Government within the last ten years had been requested.

Mr. Parsons, on behalf of the Sea-Level Canal Committee, stated that they were engaged in preparing details of the estimates of the plan which was submitted at the last meeting, and that the same would probably be ready to submit to the Board on Monday, October 30.

On motion the Board adjourned at 10.20 a. m., to meet again on Tuesday, October 31, at 10.30 a. m.

JOHN C. OAKES,
Captain, General Staff, Secretary.

NINETEENTH MEETING.

WASHINGTON, D. C., *October 31, 1905.*

The meeting was called to order at 10.10 a. m.

Present: The CHAIRMAN, and Messrs. NOBLE, PARSONS, BURR, ABBOT, STEARNS, RIPLEY, RANDOLPH, HUNTER, TINCAUZER, GUÉRARD, QUELLENNEC, and WELCKER.

The Secretary read the minutes of the seventeenth and eighteenth meetings, which were adopted.

The Chairman stated that he had received from Mr. Bunau-Varilla a letter elaborating some features of his project, copies of which had been sent by the author to the other members, and asked what disposition should be made of the paper.

It was the sense of the Board that the same should be embodied in Appendix F, as a part of Mr. Bunau-Varilla's explanation of his project.

The Chairman reported further progress for the Sea-Level Canal Committee and read a summary of estimates of quantities and cost for the proposed plan.

On suggestion of Mr. Hunter the Chairman stated that additional data respecting the beam of the larger vessels, as shown by the latest edition of Lloyd's Register, 1905–6, would be compiled for the use of the members.

The Board then proceeded to discuss the features of the proposed sea-level plan.

The project for the formation of a harbor at Colon was discussed at length. In this connection General Abbot offered the following resolution, which was adopted:

Resolved, That in view of the necessity of preparing estimates, the project for the formation of the harbor at Colon presented by the Sea-Level Canal Committee be adopted for that purpose.

At 12.55 p. m. the meeting adjourned to reassemble at 2 p. m.

The full Board reassembled at 2.10 p. m.

The Chairman stated that he had received a letter concerning unit prices from the Unit-Prices Committee.

The subject of reports of the meetings was again taken up, and after discussion it was decided that each member should be given a typewritten copy of the remarks made at the meetings, without condensation; that minutes for formal adoption should be prepared by the Secretary, by condensing and eliminating so as to state briefly the business transacted at the meetings with the action thereon; that subsequently matter of practical interest discussed at each meeting should be selected by the Board and printed in the appendixes, in addition to the minutes.

Mr. Hunter announced that some modifications had been made in the position of the tidal lock of the sea-level plan, and that the length of the jetties had been reduced to 700 feet from their former dimensions of 1,000 feet.

This led to a continuation of the discussion of the sea-level plan.

Discussion proceeded as to whether the Pacific terminus as presented by the Sea-Level Canal Committee should be adopted for the purpose of estimates, and Mr. Burr offered the following resolution, which was adopted.

Resolved, That the plan presented by the Sea-Level Canal Committee showing the location of the canal and terminal locks and the sea channel on the Pacific side—that is, that portion of the canal from kilometer 61.79 to the sea—be accepted by the Board tentatively for the purpose of estimates.

Mr. Quellennec desired his vote to be recorded in the affirmative with the modification as shown by the discussion—that he believed the alignment shown by the French plans of that portion of the canal is practicable and, possibly, preferable.

After some further discussion of the proposed method of controlling the waters contributary to the proposed sea-level canal, the Board adjourned at 4.30 p. m., to meet at 10 a. m. Friday, November 3.

JOHN C. OAKES,
Captain, General Staff, Secretary.

TWENTIETH MEETING.

WASHINGTON, D. C., *November 3, 1905.*

The meeting was called to order at 10.15 a. m. by the Chairman.

Present: The CHAIRMAN, and Messrs. NOBLE, ABBOT, STEARNS, RANDOLPH, HUNTER, TINCAUZER, GUÉRARD, QUELLENNEC, and WELCKER. Mr. RIPLEY arrived at about 11.30 a. m.

The reading of the minutes of the previous meeting was postponed.

The Chairman announced the receipt of a series of notes on the Panama Canal by Mr. John F. Wallace (see Appendix J), and stated that these notes had just been received. It had been impossible to have copies made for the benefit of the members, and suggested that it might be in order to have the Secretary read the notes after other business had been transacted.

The Chairman announced the receipt of a communication from Mr. Wallace saying that it would be impossible for him to be present at the morning session; consequently an appointment for the afternoon session at 2.30 o'clock had been made.

The Chairman announced that a list had been prepared from Laird Clowes's Naval Pocket Book, 1904, and Lloyd's Register, 1905–6, showing the number of vessels whose beam is recorded as greater than 50 feet. Copies of the list had been distributed to the members of the Board. He also announced the receipt of a cablegram from the chief engineer at the Isthmus, giving data showing the depth to rock below mean tide in the proposed channel toward the sea from the proposed tidal lock in the Ancón-Sosa saddle.

The subject of a report from the Lock-Canal Committee was discussed, and resulted in a motion by Mr. Welcker, which was adopted, as follows:

Resolved, That the Board invite the Lock-Canal Committee to place on the table at the next meeting, on Tuesday at 10 o'clock a. m., the result of their proceedings just as they are at that moment, whether finished or unfinished.

General Abbot read a resolution which he had prepared, which he intended to submit to the Lock-Canal Committee at its next session, as follows:

Whereas, in view of the language of the order of the President convening the Board "for the purpose of considering the various plans proposed to and by the Isthmian Canal Commission for the construction of a canal across the Isthmus of Panama," and in view of the fact that two such plans involving locks have been presented to the Board with all details except the enlargements of the locks demanded by the law of Congress, it is the duty of the Committee on a Lock Canal before rendering its final report to study these two plans: Therefore

Resolved, That the committee study the plan of the Comité Technique. Also, as the lock site at Bohio is too contracted to readily accommodate two locks of the large size contemplated by the law, that a variant consisting of a low dam at Gatun raising a lake to elevation about 30 feet, with a dam at Bohio and one lock raising the Bohio Lake to about 60 feet, be studied with as little delay as possible. Also that a similar study be made of the plan of the Isthmian Canal Commission contemplating an elevation of Lake Bohio to a level of 85 feet.

No action was taken upon this matter.

The Secretary then proceeded to read the papers submitted by Mr. Wallace.

Upon the termination of the reading, at 12.30 p. m., recess was taken.

The Board reassembled at 2.30 p. m.

Mr. John F. Wallace appeared and was questioned by the Board. (For statement of Mr. Wallace see Appendix J.)

The Board adjourned at 5 p. m., to meet at 10 a. m. Tuesday, November 7.

JOHN C. OAKES,
Captain, General Staff, Secretary.

TWENTY-FIRST MEETING.

WASHINGTON, D. C., *November 7, 1905.*

The meeting was called to order at 10 a. m.

Present: The CHAIRMAN, and Messrs. NOBLE, PARSONS, BURR, ABBOT, STEARNS, RIPLEY, RANDOLPH, HUNTER, TINCAUZER, GUÉRARD, QUELLENNEC, and WELCKER.

The Secretary read the minutes of the nineteenth and twentieth meetings, which were adopted.

The Secretary read the following translation of a cablegram to Mr. Quellennec referring to delay caused in the Suez Canal by the explosion of a dynamite ship:

PARIS, *November 4, 1905.*

BOARD OF CONSULTING ENGINEERS, PANAMA CANAL,
Washington:

Interruption of traffic occasioned by *Chatham* exactly ten days. Number of vessels having waited twenty-four hours or over to enter, 53 at Port Said and 56 at Suez. Number of vessels that entered canal within twenty-four hours after traffic had been reestablished, 51. Maximum number of vessels that entered canal during twenty-four hours under normal conditions since opening of canal, 36.

BONNET.

The Chairman read communications, as follows:

A letter from Mr. Maltby transmitting a blueprint showing the results of borings at the Gatun dam site.

A cablegram from Mr. Stevens giving results of borings at La Boca.

A letter from Mr. Maltby transmitting a blueprint showing plan and profile of proposed relocation of Panama Railroad.

The Chairman stated that the next business in order was the consideration of the report of the Lock-Canal Committee, containing tentative figures of quantities and cost for a canal with summit level at elevation 85. The Lock-Canal Committee were also studying two other variants of the lock-canal scheme, one with a proposed summit level at elevation 60, with a 60-foot dam at Gatun; the other with a low dam at Gatun of about 30 feet and a second dam at Bohio raising the water to 60 feet. The two variants would involve extensive calculations and study and were not completed, but would be at an early day.

Mr. Stearns, with the aid of diagrams on the wall, elaborated the 85-foot project of the Lock-Canal Committee.

Mr. Welcker submitted a paper to the Board, based on a study of the number of possible lockages per day through different sized locks proposed by various commissions and committees. (See Appendix M.)

At 12.45 o'clock the Board took recess.

The Board reassembled at 2.55 p. m.

Present: All the members of the Board.

Mr. Parsons stated that Mr. Quellennec had obtained valuable information for the Board from the offices of the Suez Canal Company, and suggested that recognition of the same be made.

It was the sense of the Board that Mr. Quellennec communicate to the Suez Canal Company the thanks of the Board for the information received.

The Chairman announced that the session, as previously arranged, would be devoted to the consideration of the report of the Unit-Prices Committee, copies of which were before the members of the Board. After a thorough discussion of the report of the Unit-Prices Committee the same was amended, and on motion of Mr. Stearns the amended report was adopted. (See Appendix R.)

The question of the transformation of the proposed lock canal into a sea-level canal was brought up, and it was the sense of the Board that the Lock-Canal Committee study this question, so far as the limited time would permit, and present to the Board their opinion as to the practicability and cost of the change.

The Chairman stated that at the next meeting of the Board the Lock-Canal and Sea-Level Canal Committees would present their plans in final shape.

On motion the Board adjourned at 5.10 o'clock, to meet Tuesday, November 14, at 10 a. m.

JOHN C. OAKES,
Captain, General Staff, Secretary.

TWENTY-SECOND MEETING.

WASHINGTON, D. C., *November 14, 1905.*

The meeting was called to order at 10.10 a. m.

Present: The CHAIRMAN, and Messrs. NOBLE, PARSONS, BURR, ABBOT, STEARNS, RIPLEY, RANDOLPH, HUNTER, TINCAUZER, GUÉRARD, QUELLENNEC, and WELCKER.

The Secretary read the minutes of the twenty-first meeting, which were adopted.

The Chairman stated that he had received that morning a letter from Mr. J. F. Wallace, stating that if the Board desired him to analyze or comment upon any data now before them he would gladly do so.

The Chairman also called attention to a blueprint on the wall illustrating a method of putting in deep foundations for a proposed Bohio dam by open excavation and ordinary mining operations, prepared by Mr. J. T. Ford, an engineer of London, England. A letter descriptive of this method had been distributed to the members.

The next business in order was the consideration of the reports of the Lock-Canal and the Sea-Level Canal Committees. The Chairman read the report of the Lock-Canal Committee and the summary of estimates of cost accompanying it. The report submitted four projects for a lock canal, as follows:

Project No. 1.—Summit level at elevation 85 feet, to be maintained by a flight of three locks at Gatun on the Atlantic side, with one lock at Pedro Miguel and two locks in flight at Sosa Hill adjoining La Boca pier on the Pacific side. Estimated cost, $141,236,000.

Project No. 2.—Same as No. 1 except that on the Pacific side there would be two locks in flight at Pedro Miguel and one at Miraflores rather than at Sosa. Estimated cost, $148,272,000.

Project No. 3.—Elevation at summit level 60 feet, maintained on the Atlantic side by a flight of two locks at Gatun, and on the Pacific side with a single lock at Pedro Miguel and another at Miraflores. For the purpose of control of the Chagres River and to furnish a water supply a dam at Gamboa was included. Total estimated cost, $171,190,000.

Project No. 4.—Summit level at elevation 60 feet, to be maintained by a dam with single locks at Gatun and Bohio on the Atlantic side, and with single locks at Pedro Miguel and Miraflores on the Pacific side, with a dam at Alhajuela. Total estimated cost, $175,929,720.

These estimates include 20 per cent for contingencies.

The Chairman also read the report by the same committee on transforming a lock canal into a sea-level canal. (See Appendix P.)

The Board discussed at length the report of the Lock-Canal Committee. It being the sense of the Board that the committee should express an opinion as to which of the four projects presented it preferred, Mr. Parsons offered the following resolution, which was adopted:

Resolved, That the report of the Lock-Canal Committee be recommitted to that committee, with the request of this Board for an expression of opinion as to the type of lock canal preferred, and that the said report be presented when the Board reassembles for the afternoon session.

At 12.35 o'clock the Board took recess.

The Board reassembled at 2.35 p. m., all members being present.

The Chairman, on behalf of the Lock-Canal Committee, reported as follows: "The Lock-Canal Committee has taken into consideration the matter referred to it by the Board at its morning session, and has the honor to report that there does not appear to be a majority of the committee favoring any one of the four projects. Three of the members have expressed a preference for project 2; the other three members expressed a preference for project 4, but two of them suggest that it would be preferable to locate the locks on the Atlantic side at San Pablo and Obispo instead of at Gatun and Bohio."

Mr. Welcker then moved as follows:

Resolved, That projects 1 and 3 be eliminated from all further deliberation.

Mr. Randolph proposed the following resolution as a substitute for Mr. Welcker's motion, viz:

Resolved, That the Board adopt the 85-foot summit level in preference to any other level for a lock canal.

Vote on the above motions was deferred.

Mr. Noble read a paper prepared by himself and Mr. Ripley on the "Traffic capacity of a lock canal with summit level at elevation 85." (See Appendix L.) A long discussion followed.

Mr. Stearns spoke at length in favor of a lock canal at elevation 85.

Mr. Burr spoke on the advantages of a sea-level over a high-level canal.

Mr. Hunter spoke, opposing a high-level canal.

The Chairman announced that a vote would be taken on Mr. Randolph's substitute for Mr. Welcker's motion.

Mr. Stearns requested that the vote be recorded.

The vote resulted as follows:

Ayes—Messrs. Ripley, Randolph, Stearns, Quellennec, and Noble.

Noes—Messrs. Hunter, Welcker, Guérard, Tincauzer, Abbot, Burr, Parsons, and the Chairman.

Mr. Randolph's resolution was defeated, 8 to 5.

Mr. Welcker then modified his previous motion to make it correspond with this vote, and submitted the following resolution:

Resolved, That project 3 of the Lock-Canal Committee be rejected, leaving only project 4 before the Board.

The vote resulted as follows:

Ayes—Messrs. Hunter, Welcker, Quellennec, Guérard, Tincauzer, Abbot, Burr, Parsons, and the Chairman.

Noes—Messrs. Ripley, Randolph, Stearns, and Noble.

Mr. Welcker's resolution was carried, 9 to 4.

At 5.45 o'clock the Board adjourned, to meet the next morning at 10.30 o'clock.

JOHN C. OAKES,
Captain, General Staff, Secretary.

TWENTY-THIRD MEETING.

WASHINGTON, D. C., *November 15, 1905.*

The meeting was called to order at 10.45 a. m.

Present: The CHAIRMAN, and Messrs. NOBLE, PARSONS, ABBOT, STEARNS, RIPLEY, RANDOLPH, HUNTER, TINCAUZER, GUÉRARD, QUELLENNEC, and WELCKER.

The Secretary read the minutes of the twenty-second meeting, which were adopted.

The Chairman stated that the Sea-Level Canal Committee had received an important paper from Mr. Randolph on "Equipment recommended for canal excavation, with capacity of each unit," based on a study of quantities, time, machines, etc. (See Appendix N.)

The Chairman reported on behalf of the Lock-Canal Committee that after having considered the question of time required for completion of the 60-foot level projects, the committee had the honor to report as follows:

The committee believes that the locks and other structures can be completed in less time than will be required to complete the Culebra cut, and that the excavation of the Culebra cut for any project will be about proportional to the volume excavated. On this basis, using Mr. Randolph's estimate of fifteen and six-tenths years for the removal of 106,700,000 cubic yards for a sea-level project with a maximum number of 100 shovels, the committee estimates the time required to build the canal with a 60-foot level at from ten to eleven years.

On motion of Mr. Parsons the Board proceeded to discuss the time necessary for the completion of a sea-level canal.

At 1 o'clock the Board took recess.

The entire Board, with the exception of Mr. Burr, reassembled at 2.40 p. m.

The Chairman laid before the Board some data he had collected during recess relating to the colored population of the West Indies. These data were collected from the best reliable sources, generally from the census reports dated 1901. The reports give in some cases the negro

population, and when the total population only is given it was assumed that 80 per cent of the total is the negro population. This percentage is much lower than is shown for those islands where the numbers are specifically given. This method of computation for the West India Islands, not including Cuba, gave a negro population of 3,932,940.

Mr. Parsons spoke on the various meanings of net tonnage as used in different parts of the world, this variance being especially applicable to the discussion at the previous meeting as showing that the net tonnage as determined by the Suez Company is about 20 per cent greater than that shown in Lloyd's Register.

The Board resumed its discussion on the time required for completing the sea-level canal.

Mr. Welcker offered the following resolution:

Resolved, That the Board declare in its report that the time of finishing a sea-level canal depends on many contingencies that can not be definitely estimated in time; that, not considering delays due to great accidents, political necessities, or faulty sanitation, and with good management, it will perhaps be possible to finish the work in about twelve or thirteen years; that unforeseen events may lengthen that period, and also favorable circumstances and first-class direction may make it possible to shorten that period by perhaps one or two years.

Mr. Stearns moved to amend Mr. Welcker's resolution by inserting the word "fifteen" in place of "twelve or thirteen."

Vote was taken on Mr. Stearns's amendment, and resulted in a tie, 6 to 6. The Chairman thereupon announced the amendment lost.

The question was then taken on Mr. Welcker's resolution, resulting in 6 votes for the affirmative and 6 for the negative, as follows:

Ayes—Messrs. Hunter, Welcker, Guérard, Tincauzer, Parsons, and the Chairman.

Noes—Messrs. Ripley, Randolph, Stearns, Quellennec, Abbot, and Noble.

The Chairman therefore announced that the motion was lost.

Messrs. Parsons and Hunter requested that record be made that although they had voted for the adoption of Mr. Welcker's resolution, yet they favored a shorter period.

It was the sense of the Board that a longitudinal profile showing the two types of canal under discussion should be prepared at once and displayed at the next meeting.

Mr. Stearns requested that the Sea-Level Canal Committee supply the Board at its next meeting with certain details relating to the control of the streams between Bohio and Obispo on the west side of the Chagres.

Mr. Hunter requested that the Lock-Canal Committee supply data showing quantities of concrete in the various works necessitated by their plan.

The Chairman announced that when the Board adjourned it would be with the understanding that the Sea-Level Canal Committee prepare the data asked for by Mr. Stearns, and that the Lock-Canal Committee prepare data respecting the total quantities of concrete, as requested by Mr. Hunter.

At 6.20 o'clock the Board adjourned, to meet Friday, November 17, at 9 a. m.

JOHN C. OAKES,
Captain, General Staff, Secretary.

TWENTY-FOURTH MEETING.

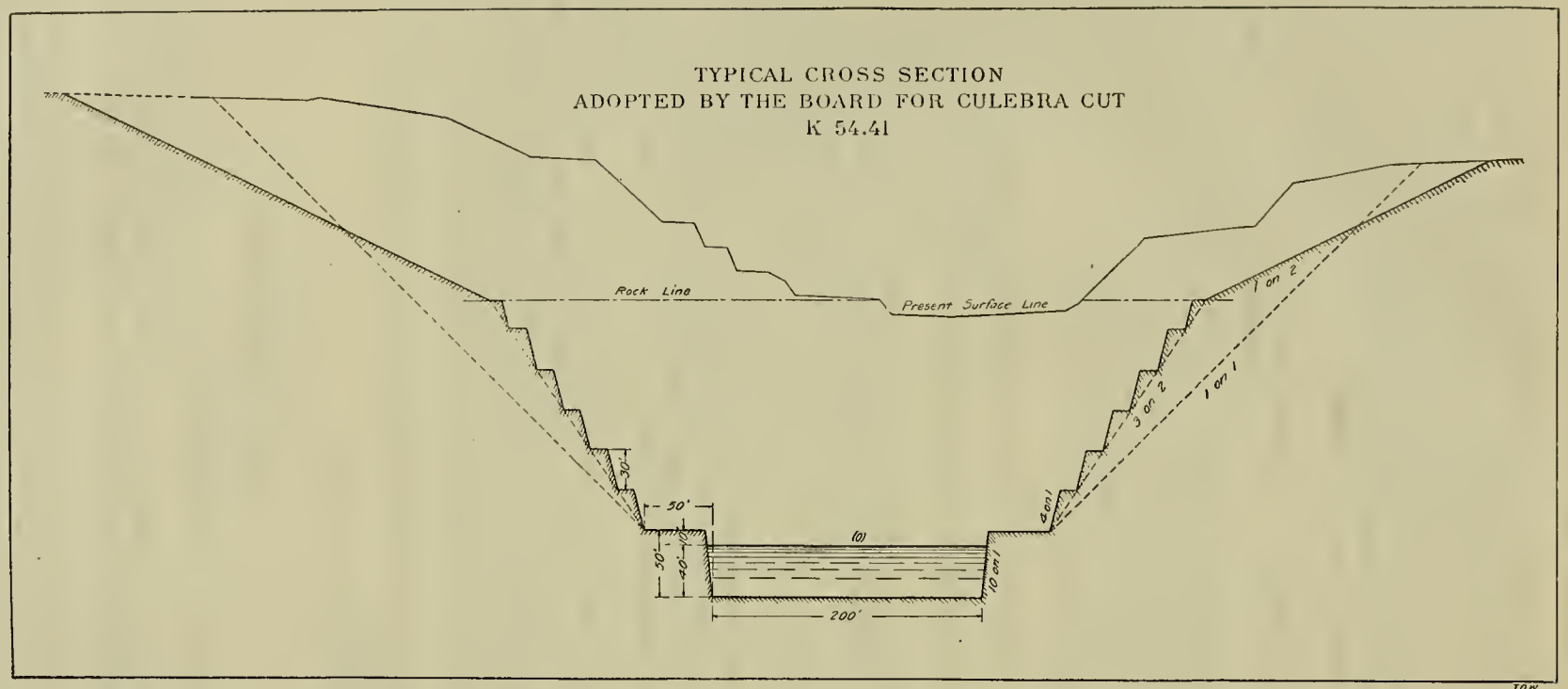
WASHINGTON, D. C., *November 17, 1905.*

The meeting was called to order at 9.25 a. m.

Present: The CHAIRMAN, and Messrs. NOBLE, PARSONS, BURR, ABBOT, STEARNS, RIPLEY, HUNTER, TINCAUZER, GUÉRARD, QUELLENNEC, and WELCKER. Mr. RANDOLPH entered at 10.45 a. m.

The Secretary read the minutes of the twenty-third meeting, which were adopted.

The Chairman read a letter received by a member of the Board from Mr. Clemens Herschel, questioning the necesssity for a tidal lock on the Panama side of the canal. No action was taken on this matter.



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The unfinished business of the preceding meeting was thereupon taken up.

Mr. Stearns submitted approximate quantities of concrete in the works pertaining to project No. 4, 60-foot summit level, for the Lock-Canal Committee, as follows:

	Cubic yards.
Gatun locks	600,000
Bohio locks	600,000
Pedro Miguel locks	910,000
Miraflores lock	490,000
Approach walls to all locks	75,000
Gatun spillway	40,000
Bohio spillway	28,000
Alhajuela dam and spillway	197,000
Total	2,940,000

Mr. Ripley then submitted the following resolution:

Resolved, That for estimating the amount of material to be excavated and removed from the canal prism the Board adopt side slopes of 1 on 1, starting at the intersection of the side channel lines with the bottom grade plane.

Considerable discussion at this point ensued.

The question was put to the Board and the resolution was lost.

Mr. Quellennec then offered the following resolution, which was adopted:

Resolved, That the cross section of the Culebra cut shown by the solid lines on the profile on the wall be approved as a typical profile for the canal where the bottom width is 200 feet. (See diagram.)

Mr. Parsons thereupon answered the questions of Mr. Stearns of the evening before about the dams across the Caño, Gigante, and Gigantito, and the diversion channels between Obispo and Bohio.

The Chairman laid before the Board the revised estimates for the sea-level project.

A long discussion then took place upon the percentage allowance for contingencies to be added to the estimates.

Mr. Stearns moved as follows:

Resolved, That we add to the estimates based upon the unit prices the sum of 20 per cent for administration, engineering, sanitation, and contingencies, exclusive of interest during construction, expenses of the Zone government, and collateral costs.

The motion was carried.

It was unanimously agreed by the members of the Board to reconsider the motion of Mr. Welcker, to determine the time of construction of the sea-level canal as proposed by the committee. The resolution was as follows:

Resolved, That the Board declare in its report that the time of finishing a sea-level canal depends on many contingencies that can not be definitely estimated in time; that, not considering delays due to great accidents, political necessities, or faulty sanitation, and with good management, it will perhaps be possible to finish the work in about twelve or thirteen years; that unforeseen events may lengthen that period, and also favorable circumstances and first-class direction may make it possible to shorten that period by perhaps one or two years.

The wording of this motion led to considerable discussion, and it was finally agreed by the Board to take a recess to allow Mr. Burr and Mr. Welcker to consult together and endeavor to come to an agreement as to a wording which would be agreeable to all concerned.

The Board took recess at 1 p. m.

The Board reassembled at 2.30 p. m., all the members being present.

Mr. Welcker thereupon offered the following resolution:

Resolved, That the Board declare in its report that the time of finishing the sea-level canal depends on many contingencies that can not be definitely estimated in time; that under efficient management and not seriously affected by extraordinary and unforeseen difficulties, political obstructions, or bad sanitation it may be regarded as feasible to complete the work in about twelve or thirteen years; that adverse conditions may lengthen that period, while favorable circumstances and continuous first-class direction may make it possible to shorten that period by one or two years.

The question was decided in the affirmative; 7 voting aye and 6 no, as follows:

Ayes—Messrs. Hunter, Welcker, Guérard, Tincauzer, Burr, Parsons, and the Chairman.

Noes—Messrs. Ripley, Randolph, Stearns, Quellennec, Abbot, and Noble.

The next business was the consideration of the dimensions and capacity of the diversion channels for the sea-level canal.

It was decided by the Board that the Sea-Level Canal Committee should review their figures as to the capacity of these diversion channels and advise the Board if any change were required.

A discussion thereupon followed about the amount of excavation in the Culebra cut.

The consideration was then taken up of project No. 4, summit level 60 feet with locks at Gatun, Bohio, Pedro Miguel, and Miraflores, and a dam for regulating the Chagres River at Alhajuela.

After considerable discussion Mr. Burr offered the following resolution, which was adopted:

Resolved, That in the judgment of this Board the dam for the control of the Chagres River and the feeding of the lock canal be located at Gamboa.

Mr. Tincauzer moved as follows:

Resolved, That the dam shall be of sufficient capacity for the Chagres control, and of such character that it be suitable for the requirements of a sea-level canal.

On this motion the vote resulted 8 in the affirmative and 5 in the negative, and it was declared carried.

Mr. Burr moved that the alignment of the Pacific terminal of the lock-canal plan be made identical with that of the sea-level plan between Miraflores and deep water.

Mr. Stearns thereupon moved as a substitute for Mr. Burr's motion the following:

Resolved, That, with the view to the adoption of one or more locks at the side of Sosa Hill near La Boca pier, the alignments for the canal be as proposed by the Lock-Canal Committee.

This motion to substitute was carried, and the question on the substitute motion was then taken and carried.

Mr. Welcker thereupon moved as follows:

Resolved, That at the Pacific end of the lock-canal project under discussion there be constructed three locks, one at Sosa, one at Miraflores, and one at Pedro Miguel, so that the whole lift between summit level and the Pacific will be accomplished by three separate locks.

Mr. Welcker's motion was lost; ayes 5, noes 8. Those voting in the affirmative were Messrs. Hunter, Welcker, Quellennec, Guérard, and Tincauzer. Those voting in the negative were Messrs. Ripley, Randolph, Stearns, Abbot, Burr, Parsons, Noble, and the Chairman.

Mr. Parsons then moved as follows:

Resolved, That the locks on the Pacific end be arranged in two single locks, one at Sosa and one at Pedro Miguel, of substantially equal lift.

The motion was carried.

Mr. Hunter moved as follows:

Resolved, That at the Atlantic end of the lock-canal project under discussion the locks be placed at San Pablo and Obispo, in order to bring the profile of the lock-canal project nearer to that of the sea-level project.

Mr. Hunter's resolution was lost, the vote being 4 in the affirmative and 9 in the negative.

Mr. Parsons then moved as follows:

Resolved, That the location of the locks as shown on the plan of the Lock-Canal Committee, one at Bohio and one at Gatun, be adopted.

The motion was carried; ayes 8, noes 5.

The Board adjourned at 6.20 p. m., to meet to-morrow, Saturday, November 18, at 9.30 a. m.

JOHN C. OAKES,
Captain, General Staff, Secretary.

TWENTY-FIFTH MEETING.

WASHINGTON, D. C., *November 18, 1905.*

The Board met at 9 o'clock a. m.

Present: All the members of the Board.

The Chairman read a letter from Mr. John F. Wallace, asking for the views of the Board on the matter of the information laid before it, as to whether it should be considered confidential. It was the sense of the Board that such information be considered confidential, and should not be published until the report of the Board was issued.

The subject of the lock-canal plan with a 60-foot summit level was then taken up and a lengthy discussion ensued. Project 4, as submitted by the Lock-Canal Committee, was the project discussed by the Board, with the modifications determined upon at the preceding meeting.

Mr. Parsons offered the following resolution:

Resolved, That for the purpose of comparison with the sea-level project, the project for a lock canal with a 60-foot summit level, and with locks and dams located as already determined by the Board, shall be adopted.

The resolution was adopted; ayes 8, noes 5, as follows:

Ayes—Messrs. Hunter, Welcker, Guérard, Tincauzer, Abbot, Burr, Parsons, and the Chairman.

Noes—Messrs. Ripley, Randolph, Stearns, Noble, and Quellennec.

Mr. Burr then offered the following resolution:

Resolved, That for the purposes of comparison with the lock-canal project, the project for the sea-level canal as already submitted to the Board by the Sea-Level Canal Committee shall be adopted.

Before voting upon this question several members of the Board gave an explanation of their proposed vote.

Mr. STEARNS. Mr. Chairman, in regard to this matter I will say that I am in accord with the general plan of the sea-level canal as being a proper project. I voted against the jetties in the bay of Limon as being something on which we had not sufficient information for forming a plan, and in some other respects I think the plan is inadequate, but I have found that there is a majority for the adoption, so I will have no further remarks to make.

Mr. QUELLENNEC. Mr. Chairman, I wish to make a remark of the same character as that made by Mr. Stearns. I favor the sea-level plan, but I am obliged to submit some objections in writing. They are only in detail, however. I will give my opinion in writing before leaving, but I am not opposed to the acceptance of the plan as a whole.

Mr. NOBLE. Mr. Chairman, I shall vote for this motion, although I do not wish to commit myself to all the details of that plan. As I understand it, this motion, if adopted, will be adopted merely for the purpose of comparing the two projects, and the principal features to be criticised are the same in both. I think for the purpose of comparison the sea-level plan may be adopted.

Mr. HUNTER. Mr. Noble is in exactly the same position that I was in with respect to the lock-canal plan. I, with him, think there are features of that plan, some very serious matters, which are objectionable; but I voted for the plan because I thought those matters had been determined and removed from discussion.

Mr. RIPLEY. I should also want to record my vote as retaining the privilege of criticism as to certain features of the plan.

Mr. RANDOLPH. I regard this plan as entirely feasible and practicable, and I believe it can be carried out within the estimates of cost. If a sea-level canal is to be built, this is a practicable route. I shall vote for this motion and vote against the sea-level project if it comes up.

General ABBOT. Mr. Chairman, I would like to state that I intend to vote for this plan simply to settle the plans for comparison. I can not be considered as favoring several details of the project.

The voting on this resolution was by roll call, and resulted in its adoption by a unanimous vote.

Mr. Tincauzer offered a motion, as follows:

Resolved, That the period of time of ten or eleven years be fixed by the Board for the completion of a lock canal adopted in the previous meeting.

Mr. Welcker offered an amendment to this motion, which was accepted, making the resolution read as follows:

Resolved, That the Board declare in its report that the time of finishing a lock canal at summit level 60 feet depends on many contingencies that can not be definitely estimated in time; that under efficient management and not seriously affected by extraordinary and unforeseen difficulties, political obstructions, or bad sanitation it may be feasible to complete the work in about ten or eleven years; that adverse conditions may lengthen that period, while favorable circumstances and continuous first-class direction may shorten that period by perhaps one or two years.

Several members expressed a desire that their votes should be modified by statements, as follows:

Mr. NOBLE. I shall vote for that resolution, but in doing so I wish it to be distinctly understood that I am not bound by any inference as to the comparative time for building the sea-level canal and the lock canal which the passage of the two resolutions might indicate. I believe that the time required for building the two canals, according to the projects before the Board, will depend almost absolutely upon the relative amounts of excavation in the Culebra cut, and I do believe that the time required for building a lock canal at a summit level of 60 feet will be substantially as indicated in the resolution.

Mr. STEARNS. Mr. Chairman, I had in mind to make the same statement.

General ABBOT. I would like to make the same statement.

Mr. RIPLEY. I also.

Mr. QUELLENNEC. I also.

Mr. RANDOLPH. I also.

Mr. HUNTER. On the other hand, Mr. Chairman, I should like to say that whereas it was asked that an expression of our opinion should be added to the preliminary resolution passed in respect to the sea-level canal—I think that addendum was not made when the resolution was passed yesterday—personally I am of the opinion that there is no reason whatever why the sea-level canal should not be constructed and easily constructed within the time suggested by this resolution, and that even if the time in this resolution be shortened, still by good management and good fortune the time would be equally shortened so far as the sea-level canal is concerned; but I am of opinion, having regard to all these works of art and the difficulty of obtaining skilled labor in the Isthmus, that of the two projects the sea-level canal could be executed first.

Mr. WELCKER. I think the chances for unfavorable and unforeseen accidents are greater with a lock canal than with a sea-level canal. I think the chances of shortening the time of construction, as expressed by our figures, are not so great in the case of the former as of the latter.

Mr. TINCAUZER. I agree with Mr. Welcker entirely.

Mr. BURR. I desire to state that while I shall vote for this motion I believe that the great quantities of work and material required in the construction of locks for a lock canal introduce a complication which more than compensates for the additional quantity of material to be taken out of the Culebra cut, and while this motion indicates a period for the construction of the lock canal less than that stated in the expression of the Board for the time required for the construction of the sea-level canal, it is my judgment that the simpler character of work would enable the latter to be constructed in a time no greater than that required for the former, and, in my judgment, even less.

The question was put to the Board, and the resolution was adopted unanimously.

Mr. Burr offered the following resolution:

Whereas, in the judgment of this Board, a sea-level canal is feasible, following a line with dimensions and such arrangements that the transit between the two oceans shall be secured in a permanent manner for all time under the best conditions for navigation and safety, for vessels of the largest tonnage and greatest draft now in use, or such as may be reasonably anticipated: Therefore

Resolved, That the Board adopt and recommend to the President of the United States the plan of a sea-level

canal with a depth of 40 feet, a width in rock of 200 feet, a minimum bottom width in earth of 150 feet, with a double tidal lock at Ancon whose usable dimensions shall be 1,000 feet in length and 100 feet in width, and with a dam at Gamboa for the control of the Chagres River.

Before voting upon this resolution the members expressed their opinions as follows:

Mr. GUÉRARD. I support in all particulars the proposition that has been submitted by Mr. Burr.

Mr. QUELLENNEC. Mr. Chairman, it is undeniable that a sea-level canal is preferable to a high-level multilock canal, both with a view of safety and facility of operation. The conditions of transit through the Suez Canal have often proved to me the many great advantages offered by a sea-level canal. Therefore, in spite of difficulties in the construction of a sea-level canal, which I have already outlined in previous statements, in spite of greater time and cost, I believe that the sea-level plan must be recommended for the reasons stated in the motion.

In stating that a sea-level canal is preferable to a lock canal I do not wish to say that a lock canal is not practicable; and, as during the discussion of the lock-canal project I have voted at times with the members of this Board who appeared to favor that plan, I request permission of the Board to justify, in a few words, my different votes and clearly explain my thoughts on the important subject submitted to us by the President of the United States.

First. From a general point of view I think that a sea-level canal is preferable to a multilock canal, and must be recommended as giving greater safety of navigation and facility of operation. But in making such recommendation I feel the necessity of showing clearly to the United States Government the great difficulties which, in my opinion, will occur in the completion of the Culebra cut.

Second. Although I recognize the dangers offered by the locks and dams in a multilock canal I am not disturbed by these dangers, which can be avoided or reduced to a minimum by both good construction and good management. Therefore I consider a multilock canal as practicable; however, I think that such a canal can be preferred only with a view of minimizing the cost and time of construction. It is for this reason that I voted for the 85-foot as preferable to the 60-foot summit level.

Third. I think also that the transformation of a high-level lock canal into a sea-level canal is a feasible operation and not presenting great difficulties if certain measures are taken at the time of construction, especially with reference to the disposition of the upstream gates, and, in my judgment, the building of separate locks instead of flights of two or three locks. I think also that such transformation can be made at less cost than is shown by the estimates presented by the Lock-Canal Committee for such transformation.

Fourth. To conclude, I prefer a sea-level canal, and I think that a lock canal should be considered only as a temporary one, built in order to minimize the amount of immediate work and first cost, and so constructed that it may be easily turned into a sea-level canal.

Consequently, in my judgment, if a lock canal should be constructed it should have separate locks and a summit level of 85 feet, obtained by adding to the 60-foot summit level plan one more lock of about 30 feet lift placed on each side of the Culebra cut near Obispo and Paraiso.

These are the reasons justifying my different votes.

Mr. TINCAUZER. I desire to say, Mr. Chairman, that my opinion has not been influenced by any person nor by the personal judgment of any person. When I vote for the sea-level canal project, and having in mind the words of the President, I vote not as I think the President of the United States may desire to have me vote, but as my best judgment causes me to vote.

Mr. WELCKER. Mr. Chairman, I have only to say to the Board that I agree with Mr. Tincauzer. I came to America with not a single fixed idea of what had to be done, and have been here all the time above all influence whatever for one type of canal or the other. The studying of isthmian conditions and of the general projects that have been presented, combined with my knowledge, little as it may be, of sea navigation and of the wants of the great navigation that is to be expected between the Pacific and the Atlantic, have brought me, step by step, to the conviction that a sea-level canal is the only one that should be considered. I repeat, with Mr. Tincauzer, that this is not due in the least to the words the President used to us in his speech

and in his remarks at Oyster Bay, but that my conviction as an honest engineer, free from all influence from any source whatever, has made me resolve at last for myself that the sea-level project is the only one that can be recommended by this Board to the American Government for execution.

Mr. NOBLE. Mr. Chairman, as between the two projects before the Board I am in favor of the construction of the lock canal, for reasons which I will state briefly, without any desire to enter into an argument at this time.

I believe the lock canal affords quicker construction; that the wider and deeper waterways it provides would give better navigation; that the transit of ships would be quicker, and that the lock canal would have even a greater capacity for traffic than the narrow waterway proposed by the Sea-Level Canal Committee.

I am entirely mindful of the injunction of the President that the design should be such as would permit the transformation of a lock canal to a sea-level canal, and I believe that when that is "ultimately required," to use the words of the President, it can be readily done. I do not believe that the lock-canal plan adopted by the Board is in all respects the best, and when I present my views at greater length, as I expect to do, I shall feel free to take up that side of the question.

General ABBOT. I concur entirely in what Mr. Noble has stated.

Mr. STEARNS. I also concur in what Mr. Noble has said. It seems to me it would be a waste of time to enter into any argument.

Mr. RANDOLPH. Mr. Chairman, I had anticipated speaking at some length upon this subject. I felt that I would like to have my views go into the record at some length, but inasmuch as there seems to be a desire that a speedy conclusion should be reached, and no more time spent upon the discussion, I simply say that I concur most heartily with Mr. Noble in what he has stated.

Mr. HUNTER. Mr. Chairman, like the other members of this Board I desire to avoid occupying unnecessary time in this discussion, but I would like to be allowed to say that my experience in the matter which has engaged the attention of the Board for so long a time has been precisely the same as that of Mr. Welcker, although the former connection which I had with the project of the Panama Canal has naturally made some difference in respect to the manner in which I reached the conclusion at which I have arrived.

I, in common with General Abbot, was a member of the Comité Technique, which the New Panama Canal Company convened in order that a plan might be prepared which the new company might at the time submit to the world and might hope to command the confidence of the world and especially of the financial world. And I feel for my part, and I am sure General Abbot feels in the same way, that I have nothing to regret in the share which I took in the preparation of that plan. I am as firm in my opinion as General Abbot is in his, that the project prepared by the Comité Technique was, under the existing circumstances at any rate, one of the best if not the best which could have been adopted. I put my name to it, and therefore I do not care to say more about it except that under like circumstances, if that committee were sitting in Paris to-day, I would subscribe to that plan again, as a whole, as I subscribed to it before. But since the date of the publication of the plan of the Comité Technique almost everything has been changed, and has been changed to so great an extent that my judgment has undergone an alteration also, so that I am now going to give my vote for the sea-level plan as against the proposal for a lock canal; and, like Mr. Welcker, the change in my opinion has been due to a process of evolution in my mind—has proceeded step by step, stage by stage.

I came to America, if I may be allowed to say so, with distinct prepossession in favor of the lock type of canal, to which I had already subscribed. The circumstances which I have met have been too strong for me, and the conclusion of the whole matter was brought about during our visit to the Isthmus. I will not enlarge upon what I have just said, and will only add that I can not undertake the responsibility of joining in a recommendation to the United States Government and to the President of the United States for the construction of a lock canal through which, from time to time, line-of-battle ships perhaps 90 feet in beam and of 20,000 tons or perhaps even 25,000 tons in displacement would be conveyed across the Isthmus of Panama by

means of a series of locks, each of which must be over 1,000 feet in length by 100 feet in width, which would form steps through which these ponderous ironclads, so difficult to handle under the most favorable circumstances, would be lifted out of one ocean in order that they might be lowered into another. Having regard to this important consideration, having regard to the safety of navigation in the everyday working of the canal, I am going to vote for the sea-level plan.

Mr. RIPLEY. Mr. Chairman, the considerations governing my choice as to the type of canal are based on the reasons stated by Mr. Noble, and also the further one that, aside from the cost of operating and maintaining the canal, the lock canal which I prefer will provide for a navigation the limit of which will not be reached in a number of years, probably forty to seventy-five years, so that the people of the United States will not soon be called upon to make additional expenditures for improving the canal; whereas for a sea-level canal it is quite probable that within a short time, possibly fifteen to twenty-five years, a widening will be necessary which will cost many millions of dollars.

Mr. PARSONS. Mr. Chairman, in deciding between the two types of canal that are before the Board I am going to be governed in my vote by what seems to be proper for the Government of this country to do. If this were a commercial enterprise for a private company I should vote for a lock canal, as I believe a lock canal can be built for less money and probably in less time, consequently giving a better chance for profit on the enterprise, and will also answer the practical requirements of commerce for some years to come.

But that is not the question, it seems to me, which is before this Board. We are to adopt a project for all time to come, a work of the greatest constructive magnitude that has ever been undertaken, and for at least one of the most powerful governments in the world.

The plan, therefore, should be of the broadest and largest possible type which we can conceive. The question whether it is to take a few years more or less seems to me to be one of very small consequence. Nor is the question of the additional money required, whether that money be $50,000,000, $75,000,000, or even $100,000,000, one of importance, as there is to be an adequate return.

We have heard a good deal in the discussions of the Board as regards the danger with locks, and of the accidents that have occurred in the Manchester and "Soo" canals. Similar accidents have occurred in the Welland and other canals. So far those accidents have, by great good fortune, been limited to accidents and have escaped being disasters. They were all accidents, however, with locks of comparatively small size. With locks of the size now contemplated the results would have been more serious.

It is not the danger to the ship itself that I have in mind, because the difference in insurance risks that would be charged to a vessel, whether she were going through one type of canal or the other, would probably not be very much, but I have in mind the danger to the canal. If at one of these big locks an accident should happen such as has happened at other locks, and as will happen here, and a ship should go plunging through and carry away the safety gates and guard gates and every other mechanical device of protection, releasing the lake of water that lies behind those locks, the section of the canal between that lock and the ocean terminus would be so destroyed that it would take anywhere from one to five years to put it back in service again. The terminal port itself would be gone, the canal would be out of use, the world's traffic would be deranged, and the difference in cost between the two types would be wiped out in a few seconds of time. That risk a great government can not be justified in taking.

In building the great railways or other great enterprises of the world there is scarcely a case where the projectors have overshot the mark. They have always regretted afterwards that they did not build to a larger size than that first projected, and I am sure that is going to be true here. The canal should be built at once at sea level.

Mr. BURR. Mr. Chairman, I shall take this opportunity to make no argument, but simply to state briefly some of the considerations which induce me to cast my vote for the resolution.

I have passed through much the same progressive conditions of mind as have Mr. Hunter and others who have been brought to regard the sea-level plan as a proper one for a ship waterway

across the Isthmus of Panama. In starting the investigation over six years ago which finally closed in the selection of the Panama route, my leaning, so far as I had any, was certainly in favor of a lock canal. The lock type had, in a measure, become what may be called the American type, because the Nicaragua route was then popularly considered to be an American line, and the lock plan only is feasible for that route.

It required, however, but a short investigation to satisfy me, as it did other members of the first Isthmian Canal Commission, that the Panama route was by far the most practicable and feasible for a ship canal across the American Isthmus. For purposes of comparison at that time it was practically necessary to adopt a lock plan for the Panama route, but after repeated examinations of the locality, after consideration long extended of all the circumstances attending this great enterprise, I was led, as others have been, gradually but inevitably to the conclusion that the sea-level plan should be adopted.

The simplest waterway between the two oceans is clearly an open canal from one tidewater to the other. Locks are perfectly feasible and in many cases absolutely necessary, but, in my judgment, on this waterway, where there should be the freest connection between the two oceans, obstructions or restrictions of all kinds should be reduced to an absolute minimum within the feasibility of cost and time to accomplish that end. The additional time taken to pass through locks, as the President has well said, is a matter of no real consequence, but the hazards that are incurred in passing through a series of three or four or four or five locks are, to my mind, of the gravest import.

The additional cost of the sea-level canal is not largely in excess of that of a lock canal, and the difference is a matter of no consequence to this Government, provided the expenditures are made honestly and provided there is a return for the money so expended.

I am strongly of the opinion that even in the terminal-lake plan, which has been so admirably studied and set forth by members of the Board, the time required in passing the locks will more than neutralize the advantage of increased speed which may be attained between them. It has therefore been borne in upon my mind with irresistible force that it would be far better in constructing a waterway which must answer the commercial purposes of all time and the naval requirements of the Government to make that waterway as nearly absolutely free of risks of all classes, of obstructive features to future enlargement and of all restricting conditions, as possible, and those results will be obtained by the adoption of the sea-level plan, with a period of construction which will be extended but little if any beyond that necessary for a lock plan.

I wish finally to express my realization of the honor and privilege of submitting this resolution at the gracious suggestion of some of my colleagues whose delicate courtesy I highly appreciate.

The CHAIRMAN. Gentlemen, I wish to state some of the reasons which have constrained me to adopt the course I have in voting in the past, and the intention I have of voting for this resolution.

As a schoolboy I learned, in the study of geography, that there were two great points of interest for navigators in the world which sometime would be overcome. One was at Suez and the other at the isthmus connecting North and South America. Until recently we knew very little about isthmian physical conditions; but more direct communication by water than nature provided was called for, and finally these demands began to take concrete shape. It was not, however, until the late fifties that any serious attempt was made to connect the Mediterranean and the Red Sea, and then that work was essayed by a corporation with private capital. The opponents of this scheme were many and earnest. A great many vessel owners alleged that the canal navigation would be unsafe, and many eminent engineers asserted that the desert sands would be drifted by the winds into the excavation as rapidly as the earth could be removed. There were no harbors, and no potable fresh water for use by the workmen could be had save that brought by camels. One or more of the great world powers were opposed to the making of any canal at all, and no European government lent its credit to the undertaking or in any way facilitated its financial arrangements.

The projectors of the enterprise proposed to do the principal work by manual labor, and for

several years excavating machinery and steam power in earth removal were little used; but the needed machines were in due time invented and proved to be of the greatest possible utility, saving vast sums of money, much time, and sparing the further necessity of depending on forced labor.

The task that confronted the private company that essayed that work, measured by the difficulties they had to encounter, was many times greater, it seems to me, than the task which, measured by the standard of engineering methods and capabilities that exist to-day, confronts the United States at Panama: but the French company carried that work to completion at Suez thirty-six years ago, and it has yielded enormous profits to its owners. The many difficulties were overcome and an open waterway was made 100 miles long, affording unobstructed navigation for commercial and war vessels, all except those of the very largest dimensions; but the work of enlargement of the channel so as to accommodate vessels of exceptional size is being carried forward as the navigation needs require, and the traffic is never interrupted.

The United States Government must surmount only physical difficulties, and fortunately these are now so well known that the element of uncertainty is reduced to small limits.

We know that at Panama to make a waterway similar to the Suez Canal we must construct a channel less than half as long, but we have to surmount an original elevation of some 300 feet. Should the United States withdraw from the attempt to make at the American Isthmus a channel as open, free, and safe as that already existing at Suez? Should they climb over the hill or should they remove it? It seems to me a channel should be opened through those seven or eight miles. I think the dignity and power of this great nation, of which some of us are proud to be citizens, require that we should treat this matter not in a provisional but in a final, a masterly way.

The lion in the path, about which there has been a great deal said for all these years, is the Chagres River—the difficulty, the impossibility even of controlling it. Now, what has been and is being done in respect to river control in America, in Europe, in Asia, in Africa? We know that rivers of very considerable magnitude, perhaps not carrying quite so great a flood volume as the Chagres but still carrying very large volumes of water, have already been obliterated as rivers in their lower courses. They no longer menace anything or anybody, but the water serves a beneficial purpose by its distribution over agricultural land. One of the largest rivers in the world, the Nile, having a measured flood discharge many times greater than the gauged or estimated flow of the Chagres, has come under the complete control of men by works that were easily accomplished in less time than the engineers estimated.

I have the feeling that the Chagres control will be easily attained, in the sense we use the words respecting the attainment of large things, and that difficulty, to my mind, is of less and less importance as we better understand the conditions. A few years ago we knew little about it, but now the physics and hydraulics of this stream are probably as well known as those of any river in the world, and we can measure the due proportion and outlay for works for its control. It may, perhaps, cost as much as it did to make the dam at Assuan, on the Nile.

The only other feature of the work at Panama that in the opinion of some presents difficulty and involves uncertainty is the deep cutting at Culebra summit. The French have excavated there to a depth of more than 150 feet, and to reach tide level an excavation of as much more is necessary. Assuming that the side slopes of this trench will be stable and secure at the same angle of repose that nature has provided on the sides of a dozen or more hills in the immediate vicinity of Culebra and apparently of the same formation, it will be necessary to remove certain quantities of earth and rock to make effective a sea-level channel through this summit region 200 feet wide and 40 feet deep below mean tide. If this mass is removed at a rate no greater than has already been attained on other works it will take ten or eleven years to do it. With improvements over existing methods as effective as were developed during the making of the Suez and Chicago Drainage canals the time for completion will be shorter and the cost proportionately less.

If a canal existed at Panama with the capacity of the Suez it would fairly meet present needs. Almost all the vessels now in commercial employment, and the navies of the world,

would be accommodated; but as the Government has undertaken the work at Panama, a work for all time. I am not satisfied to advise that a bottom width of 115 feet is sufficient. We propose the greater minimum width of 150 feet and a depth nearly a third greater than at Suez. As the years go by and the necessity arises we may have to do exactly what is now being done to almost every existing great ship canal and harbor entrance—widen and deepen the waterway.

What do we see in railroad construction? Corporations that organize to build railroads frequently have a limited capital. Some roads must cross mountain ranges, and by what method? They climb over those ranges at first; they put in parallel tangents, sharp curves, loops, and switch-backs, and in some way they get over. They climb the steep grades and incur the heavy expense of the steep haul—and it imposes a heavy charge upon the cost of operating—but just as soon as the road has means to do it, it drives a tunnel through the mountains or deepens the cutting. The Alps are pierced now in several places, as you all know. Other ranges have been and are being pierced.

One of the last works of the present chief engineer of the Panama Canal was to drive a railroad tunnel through the Cascade Mountains, so as to decrease grades and more nearly approach sea level.

These are some of the reasons why I vote as I do.

The question of the adoption of the resolution was put to the Board, and it was agreed to; ayes 8, noes 5, as follows:

Ayes—Messrs. Hunter, Welcker, Quellennec, Guérard, Tincauzer, Burr, Parsons, and the Chairman.

Noes—Messrs. Ripley, Randolph, Stearns, Abbot, and Noble.

There followed a lengthy discussion of what the report should contain, which was terminated by a motion of Mr. Burr to appoint a committee of three, of which the Chairman should be one, to draft the report.

The motion was carried unanimously.

The Chairman appointed Messrs. Noble and Burr as his colleagues on that committee.

At 12.50 p. m. the Board took recess.

The Board reassembled at 2.30 p. m.

Present: All the members of the Board.

The committee for drafting the report made a preliminary statement of what they thought should be in the report.

A discussion then followed upon the question of sanitation on the Isthmus, and some extracts from reports of the chief sanitary officer were read showing that yellow fever had decreased very rapidly, until during the month of October only 3 cases occured in the Zone. (See Appendix O.)

A request from Mr. Wallace that 1,000 copies of his notes be printed and sent to him (at his expense) was read to the Board, and a discussion ensued as to the propriety of doing this before the report should be finished and handed to the President of the United States. It was decided that the Board has no objection to Mr. Wallace printing the notes he turned in here for his own use, but that the Board could not furnish him with any of the record of the Board in advance of its publication.

The discussion of the projects of Messrs. Bunau-Varilla and Bates then ensued.

Mr. Noble moved as follows:

Resolved, That after a careful consideration it is the sense of the Board that the adoption of the plan of either Mr. Bunau-Varilla or Mr. Bates is not expedient.

The motion was carried unanimously.

The meeting adjourned at 3.45 p. m., to meet on Thursday, November 23, at 9.30 a. m.

JOHN C. OAKES,
Captain, General Staff, Secretary.

TWENTY-SIXTH MEETING.

WASHINGTON, D. C., *November 23, 1905.*

The meeting was called to order at 9.50 a. m.

Present: The CHAIRMAN, and Messrs. NOBLE, PARSONS, BURR, ABBOT, STEARNS, RIPLEY, RANDOLPH, TINCAUZER, GUÉRARD, QUELLENNEC, WELCKER, and HUNTER.

The Secretary read the minutes of the twenty-fourth meeting, which were corrected and adopted.

The Chairman stated that Mr. Guérard had prepared two papers on the terminal features of the canal, to facilitate the work of the Report Committee.

The Secretary read drafts of the preliminary reports prepared by Mr. Burr, viz, "Work done and present conditions," "The control of the Chagres River," and "Harbors." The papers were discussed and amplified.

A paper prepared by Mr. Hunter on "Capacity of canal for traffic" was treated likewise.

A discussion took place about the amount of time the gates of the tidal locks could be left open.

The Board then entered into a lengthy discussion of the different phases of its report, with a view to facilitating the work of the Report Committee.

It was the sense of the Board that the Report Committee submit at the next meeting a list of headings of the principal topics to be brought up in the report, in order that the Board might cover a wide range in its discussion and thus assist the committee in drawing the report.

At 1 p. m. the Board adjourned, to meet to-morrow afternoon at 2 o'clock.

JOHN C. OAKES,
Captain, General Staff, Secretary.

TWENTY-SEVENTH MEETING.

WASHINGTON, D. C., *November 24, 1905.*

The meeting was called to order at 2.15 p. m.

Present: All the members of the Board.

The Secretary read the minutes of the twenty-fifth and twenty-sixth meetings which were adopted.

The discussion on the report of the Board was resumed.

Mr. Ripley moved the adoption of the report of the Lock-Canal Committee on the transformation of a lock canal into a sea-level canal.

The motion was adopted. (See Appendix P.)

Mr. Hunter moved that the chapter prepared by Mr. Noble on the history of the Panama Canal be embodied in the report.

The motion was adopted. (See Appendix Q.)

The Board discussed the projects of Mr. Lindon W. Bates, and it was the sense of the meeting that the quantities contained therein should be checked.

The Board then discussed the question of maps to accompany its report, and it was the sense of the Board that the report should be accompanied by a map of the canal territory similar to that adopted by the Comité Technique, and that there should also be included other maps where such are deemed necessary to illustrate certain points.

The method of putting in the estimates was then discussed, and it was the general opinion of the members that a course similar to that adopted by the Commission of 1899–1901 should be followed.

It was further agreed that the Board should embody in its report a brief review of the work accomplished and a record of the votes on the important transactions.

Mr. Parsons then moved the following resolution, which was adopted:

Resolved, That when this Board adjourns it adjourn subject to the call of the Chairman, both as to time and place, and that four members shall constitute a quorum for the transaction of business.

Mr. Hunter, on behalf of the Board, presented the following resolution, which was unanimously adopted:

Resolved, That the very best thanks of this Board be conveyed to General Davis for his most excellent conduct in the chair.

After a series of farewell speeches in which each of the foreign members participated, and responses by Mr. Randolph and the Chairman, the Board adjourned at 5.03 o'clock, subject to call.

JOHN C. OAKES,
Captain, General Staff, Secretary.

TWENTY-EIGHTH MEETING.

WASHINGTON, D. C., *December 5, 1905.*

The meeting was called to order at 10 a. m.

Present: The CHAIRMAN, and Messrs. NOBLE, PARSONS, BURR, ABBOT, STEARNS, RIPLEY, RANDOLPH, and QUELLENNEC.

The Secretary read the minutes of the twenty-seventh meeting, which were adopted.

The matter of editing the records of the Board which will be printed was taken under consideration and Mr. Burr suggested that a committee of three should be appointed for that purpose.

After a thorough discussion of the matter Mr. Parsons offered the following resolution, which was adopted:

Resolved, That the Chair appoint a committee of three, of which he shall be one, to cooperate with the Secretary in the preparation of the printed records of the meetings of this Board.

In accordance with the preceding resolution the Chairman named Messrs. Ripley and Parsons to serve on the committee.

The Chairman stated he had received communications from Mr. John F. Wallace respecting his previous remarks and would lay the same before the Board on another occasion.

The Chairman stated that he had directed Mr. Bertoncini to prepare a copy of the map of the Comité Technique showing the line of the canal with the kilometer distances marked thereon, to be used for the basic purpose of illustrating the sea-level plan. It was the sense of the Board that the map should also show the mile marks, the point of origin being taken as the end of the jetties in Colon Harbor.

Mr. Noble read a draft of a chapter he had prepared for the report entitled "Transformation of a lock canal into a sea-level canal." It was the sense of the Board that this should be embodied in its report.

The Chairman read a letter received from the Chief of the Bureau of Intelligence of the Navy Department giving data in respect to some of the larger war ships now in the course of construction.

The Chairman then read two chapters he had prepared for the report, at the request of the Board, entitled "Climate" and "Sanitation."

At 1.05 p. m. the Board took recess.

The Board reassembled at 2.50 p. m.

Present: The CHAIRMAN, and Messrs. NOBLE, PARSONS, BURR, ABBOT, STEARNS, RIPLEY, RANDOLPH, and QUELLENNEC.

The Chairman read another chapter he had prepared for the report entitled "Military and naval aspects."

Mr. Quellennec read for the information of the Board a cablegram the Chairman had received

from the Suez Canal Company, giving information concerning health conditions at Ismaïlia, as follows:

[Translation.]

PARIS, *December 5, 1905.*

CHAIRMAN BOARD OF CONSULTING ENGINEERS, PANAMA CANAL,
Washington.

Population Ismaïlia 9,000, of which 2,000 are Europeans; average annual cases malaria 1,400 before sanitation by Ross;[a] 1903, cases 214; 1904, cases 90; 10 months 1905, cases 44. These last three numbers relate only to those having had malaria before sanitation by Ross. No death from malaria. Previous statistics do not record deaths attributable directly to malaria.

BONNET.

It was the sense of the Board that in order to hasten the preparation of the final report, a preliminary draft of the entire report should be furnished each member at least one day previous to the next meeting.

The Board adjourned at 4 o'clock, to meet subject to the call of the Chairman as to time and place.

JOHN C. OAKES,
Captain, General Staff, Secretary.

TWENTY-NINTH MEETING.

1 WEST THIRTY-FOURTH STREET, NEW YORK, N. Y., *December 17, 1905.*

The meeting was called to order at 2.15 p. m.

Present: The CHAIRMAN, and Messrs. NOBLE, PARSONS, BURR, ABBOT, STEARNS, and RIPLEY

The Secretary read the minutes of the twenty-eight meeting, which were adopted.

At the request of the Chairman, the Secretary made a detailed statement of progress in formulating the report, and the remainder of the session was occupied in a discussion and final preparation of the same.

Toward the close of the meeting the following resolutions were presented and adopted:

Resolved, That the thanks of the Board are extended to Capt. John C. Oakes, General Staff, U. S. Army, the Secretary, for his valuable services and careful attention to the requirements of the Board.

Resolved, That it is the sense of this Board that a letter be addressed to the Chairman of the Isthmian Canal Commission expressive of the Board's appreciation of the valuable assistance rendered it in the discharge of its duties by Mr. Charles Bertoncini, chief of division of map making and lithography, at Panama, and by Mr. Edward B. Harden, chief draftsman of the Commission in Washington. The work of these accomplished draftsmen was of very great value to the Board.

At 5.15 p. m. the Board adjourned, subject to the call of the Chairman.

JOHN C. OAKES,
Captain, General Staff, Secretary.

THIRTIETH MEETING.

60 WALL STREET, *New York, January 31, 1906.*

The meeting was called to order at 11.05 a. m. by the Chairman.

Present: The CHAIRMAN, and Messrs. NOBLE, BURR, PARSONS, ABBOT, STEARNS, RIPLEY, and RANDOLPH.

The Secretary read the minutes of the previous meeting, which were adopted.

The Chairman read a letter addressed by him to the Board relative to his trip to Europe and

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[a] Sanitation completed in 1902.

the signing of the report by the foreign members and of the changes made therein. The letter was ordered to be incorporated in the minutes and is as follows:

WASHINGTON, D. C., *January 30, 1906.*

THE BOARD OF CONSULTING ENGINEERS FOR THE PANAMA CANAL.

GENTLEMEN: I have the honor to report that I have carried into effect the desire expressed by the Board before the departure of the European members for their homes, that I should proceed to Europe and submit to those members a copy of the report as drafted by the American members and obtain signatures to the same.

The journey to Europe was made in pursuance of specific authority of the Secretary of War, and a copy of the report as drafted before my departure was placed in his hands.

I left New York for Cherbourg on December 30, reached Paris January 7, and on January 9 proceeded to Brussels, where all the European members were assembled. After careful reading, several verbal and a few more important amendments and corrections were made, and the report was signed by all the European members on January 10. The date, January 10, was inserted as the date of the report itself.

I returned to Paris, where it was necessary for me to again see Mr. Quellennec, and sent cables to the Secretary of War and to the Secretary of the Board announcing the result of the journey. Sailing from Liverpool on January 17, I reached New York on the 25th of the same month.

I have the honor to lay before the Board the report as corrected, which includes the views of the minority, which have not been heretofore presented. If this report now laid before you, with appendix matter, and with maps with which you are all familiar, meets with your approval, I suggest the enactment of a resolution authorizing me, as Chairman, to submit this document as the final official opinion of the Board, including the views of the minority—this document to take the place of all previous drafts, records, or memoranda that have from time to time been printed or typewritten for the use of the Board.

Very respectfully, GEO. W. DAVIS, *Chairman.*

Mr. Noble offered the following resolution, which was adopted:

Resolved, That the Chairman be authorized, on behalf of the Board of Consulting Engineers, to deliver to the proper authority a certified copy of the report of the Board, including the views of the minority, together with all appendix matter that has been prepared for publication and a further appendix consisting of 31 plates, maps, and diagrams, and to state that the document now submitted contains the final official opinion of the Board respecting the types of canal favored by the majority and the minority; and that these documents, including the appendix matter and the maps, are to take the place of all previous drafts, records, or memoranda that have from time to time been printed or typewritten for the use of the Board.

After considerable discussion of the estimates submitted in the report with reference to the 20 per cent allowance for contingencies, etc., Mr. Parsons moved a reconsideration of the following resolution, which was adopted during the twenty-fourth meeting:

Resolved, That we add to the estimates based upon the unit prices the sum of 20 per cent for administration, engineering, sanitation, and contingencies, exclusive of interest during construction, expenses of the Zone government, and collateral costs.

The motion to reconsider the resolution was carried unanimously.

Mr. Burr then moved to amend the resolution, to make it read as follows:

Resolved, That we add to the estimates based upon the unit prices the sum of 20 per cent for administration, engineering, and contingencies, exclusive of interest during construction, sanitation, expenses of the Zone government, and collateral costs.

The motion to amend was unanimously adopted.

The resolution as amended was then adopted by the unanimous vote of the Board.

The minutes of the present meeting were then prepared and read to the Board and adopted.

Thereupon the Board adjourned sine die.

JOHN C. OAKES,
Captain, General Staff. Secretary.

Appendix B.

A GEOLOGICAL STUDY OF THE ISTHMUS OF PANAMA.

By Mr. Marcel Bertrand,
Member of the Institute of France; Professor of Geology at the National High School of Mines at Paris, and

Mr. Philippe Zürcher,
Chief Engineer in the Corps of Bridges and Routes of Communications of France.

[Translation by Capt. John C. Oakes, U. S. Army.]

GEOLOGICAL SECTION OF THE ISTHMUS.

Preliminary work.—The real basis of our knowledge concerning the age of the strata of Panama is to be found in two publications by Mr. Douvillé (March, 1891, and December, 1898). The first of these notes was based on the examination of a series of fossil specimens collected by Mr. Canelle, late engineer of the canal company. The second, of which only a résumé has so far appeared, begins the study of the fossils which were reported by Mr. Zürcher.

We have also used an important treatise by Mr. Hill, published in 1898, giving an account of an expedition to the Isthmus and to Costa Rica in 1895. The fossils collected by Mr. Hill have been determined by Mr. Dall, who gives a greater age to the region of the Isthmus than Mr. Douvillé; this discrepancy seems to be especially founded on certain misunderstandings as to the assimilation with the European fauna. As to stratification, Mr. Hill had knowledge of only a very small part of the data furnished by the borings at the canal site. These data have led us to modify considerably the conclusions of Mr. Hill concerning the age of the eruptive rocks of the Isthmus.

We must mention, moreover, the memoir of Mr. Wagner, which contains few valuable conclusions concerning the age of the land or the rocks, but which does furnish some valuable data about the topography and the lay of the strata of the contiguous region. Mr. Wagner is the only geologist whose explorations have extended a considerable distance from the axis of the canal.

Finally, we have made use of the memoir of Mr. Boutan, which is especially important in studying the eruptive rocks, and the geological description of the surveying commission of 1884. All of these documents have been compared with one another, and have been completed by a comparison with the shafts and borings which were made by the old and the new companies. As to the borings of the former company, it should be mentioned that we have not had the collected specimens at our disposal, but we are sure that the criticism of the ancient geological profile, drawn up at the time of stoppage of the work of the old company, was much exaggerated, and that the designations, although often little conforming with the usual designations, were nevertheless in perfect relation and can therefore be used to advantage. Besides the numerous shafts sunk by the new company along the whole central trench, shafts, the specimens from which were seen on the premises by Mr. Zürcher and studied by us in Paris, are sufficient, we believe, to assure a considerable certainty to our principal conclusions about the strata.

The microscopic studies were made at l'École de Mines, by Mr. Termier, professor of mineralogy, for the rocks, and by Mr. Cayeux, demonstrator of geology, for the Culebra terrain. The fossils, as we have said, were determined by Mr. Douvillé.

General structure—The Gamboa rock.—The oldest formations were found in the central part of the Isthmus, where their horizontal position forms a large undulating plateau, slightly inclined in its whole extent toward the Atlantic and dipping quite rapidly at its two extremities under the more recent sedimentary strata. The general aspect is therefore that of a wide, low, anticlinal arch.

The central part is formed by the volcanic rock of Gamboa, which presents itself almost everywhere as breccia, the cement of which is clearly eruptive, and often of an entirely analogous nature to that of the embedded fragments. True overflows of eruptive rock alternate with the breccias. According to Mr. Hill there are two distinct formations, and at Matachin the breccias can be seen resting uncomformably on the massive rock. Such unconformities are, at the same time, very difficult to ascertain and of little significance. However, everything seemed to us to show an intimate connection between the overflows and breccias.

The probable age of these rocks can be determined from the following considerations: On one hand, on the southwest slope, toward Obispo, we are unable to perceive any clear demarcation between the upper breccias, mixed with the volcanic rock, and those which form a part of the Aquitanian series of the Culebra; on the other hand, andesitic flows, intercalated in this Aquitanian series, are identical with certain elements of the Gamboa rock; finally, a more precise fact is furnished by the nummulites and the orbitoïdes which Mr. Douvillé recognized near Bohio.

The outcrops of Bohio are not, it is true, in continuity with the principal outcrop of the Gamboa rock, which along the plain of Tavernilla is overlain with trachytic tuff. They have, moreover, partly the appearance of conglomerates altered by water; thus, in the rocks of the banks of the Chagres River a part of the embedded fragments, rounded or angular, seem to be rocks of a peculiar aspect and of a strange origin. It should be noticed, however, that a microscopic examination reduces the difference and seems to show that they are rocks of the same composition, but consolidated at a greater depth and torn off from a neighboring crater. At least the breccias of the quarry of Bohio, formerly worked for the railroad construction, have a less decomposed cement, which permits their clearly eruptive nature to be established. It is, as Mr. Boutan says, a true solidified volcanic mud.

The association of the breccias of Bohio with the Gamboa formation seems to us unquestionable; and, on the other hand, it is certain that under these breccias the boring at kilometer 24.36 discovered strata containing nummulites. These are very small, of the Oligocene type, and they are associated with orbitoïdes, which seem to be the same as those of the Aquitanian limestone formation of Peña Blanca. There is, therefore, a confirmation of the gradual change indicated on the other slope of the anticlinal arch. The Gamboa rock is certainly Oligocene and probably Aquitanian.

It is important to clearly specify that, Tongrian or Aquitanian, the Gamboa rock represents the oldest formation of the Isthmus. Wagner has spoken of Permian sandstone on the Pacific coast, but this is only tuff and trachytic breccias reddened by decomposition. Mr. Hill is tempted to assign this tuff to the Cretaceous age. We shall see that they are clearly superposed on the Gamboa rock and even on the fossiliferous Miocene limestone.

Atlantic slope.—If, taking the breccia and the associated nummulitic strata as a starting point, we pass toward Colon on the Atlantic we meet with a series of marine strata of an age more and more recent as we approach the coast.

These are first glauconitic clays, rich in Foraminifera and full of débris of the neighboring volcanic rock. Mr. Hill says that near Peña Negra these clays lie in discordance against the breccias.

It seems probable, from what precedes, that this nonconformity is local and due to a change of the course of the waters rather than to the movements of the strata. Mr. Dall determines the fossils of these clays to be Oligocene.

These strata, from which we get no fossils, have, moreover, an imperfect development. They are almost immediately overlaid by the orbitoïdes limestone of the Peña Blanca. "These orbitoïdes," says Mr. Douvillé, "belong to the genus 'Lepidocyclina,' Gümbel; furthermore, all

the species known of this genus belong to the Oligocene period: *O. Mantelli* of Alabama and of the Tongrian of Malta, *O. dilatata* of the Tongrian of Piemont, *O. burdigalensis* of the Aquitanian of Merginac, and finally various forms of *O. elephantina*, discovered by Mr. Munier-Chalmas in the Aquitanian of Vicenza." The orbitoïdes of Peña Blanca are accompanied by nullipores and by the large flat heterostegines.

Farther up, near kilometers 20.15 and 13.50, Mr. Hill indicates, under the names of the strata of Vamos-Vamos, layers of dark color, rich in volcanic débris and containing large calcareous concretions in which fossils are found. The layers are always dislocated or slightly corrugated. The visible slopes are always toward the Atlantic.

Mr. Dall determined the fossils of these strata to be Eocene (Claiborne). Our specimens contain nothing determinable, but, as Mr. Hill says, the superposition on the strata containing orbitoïdes is incontestable, and the succession is, moreover, very similar to that of Jamaica. We have placed this series in the Aquitanian, connecting it provisionally with the limestone of Peña Blanca.

Near Gatun (km. 10) more sandy banks exist with the imprints of leaves, the *Turritella tornata*. This very specialized form is one of the Miocene of the Antilles. It occurs again on the Isthmus at several points, associated, as we shall see, with the *Pecten subpleuronectes*, and with Clypeasters, i. e., a clearly Miocene fauna. On it lie marls, sometimes glauconeous, sometimes with an appearance of tuff, less rich in volcanic débris, but containing débris of feldspar and especially of orthose. They seem to make up from top to bottom the neighboring hills (Mindi Hills, Sierra Quebrancha). The fauna, very rich and very well preserved, is that of the Miocene of the Antilles. The strata, which are above those of Gatun, must belong like them to the lower Miocene period.

Thus we find on the Atlantic slope, forming the northeast of the anticlinal arch, a series clearly marine, containing débris of the oldest eruptive rocks without the interjection of contemporaneous lava flows.

This series, perfectly continuous, passes from the Aquitanian to the lower Miocene; the strata are generally inclined toward the Atlantic, but become horizontal as they approach this coast.

Southwest slope—Culebra cut.—If now, reserving the study of the intermediate outcrops, we pass to the other side of the central arch we find a series almost symmetrical with the preceding, but which differs from it by some marine intercalations and by the presence of numerous eruptive rocks.

The basis of this new series is made up either by altered breccias, which the data we had at our disposal did not allow us to separate with certainty from the volcanic breccia, or by bituminous schists, rich in volcanic débris. The first appearance of the latter occurs near kilometer 43.70, a little in advance of Matachin, in a depression of the Gamboa rock. A second outcrop at kilometer 48.60, beyond Las Cascadas, is very thin and interposed between breccia and fossiliferous limestone, of which we shall speak later; finally, it is only beyond Emperador, at kilometer 51.50, that the Gamboa rock sinks definitely in depth and shows a system of at least 60 meters (196.85 ft.) thick of bituminous schist and grit. It is these through which the canal at Culebra has to be dug. There are numerous imprints of plants, and in places débris of some Foraminifera, among which Mr. Cayeux recognized cuts of globigerina and textularia, but concerning their age the only certain fact is that at kilometer 49 the schists are overlaid by thick limestone, forming here and there lumachel of *Ostrea*, *Pecten*, and *Cardium*, and containing the *Pecten subpleuronectes*. This limestone is Miocene (Bordeaux) and similar to the strata of Gatun. It is therefore quite natural to see in the schists an equivalent of the strata of Vamos-Vamos or of the Aquitanian. At various other points strata with oyster shells reappear at the top of the section and include rounded orbitoïdes (km. 52.50–53). At kilometers 53.68 and 53.87 there are more orbitoïdes.

Between the Miocene limestone and the subjacent layers there is no clear line of demarcation. The bituminous clays and schists change gradually into the calcareous "mollasse" (Fr.) and to the upper lumachels. The marine or coastwise layers, which are shown by lignitic traces

and the vegetable imprints of the schists, are above the limestone and produce (km. 49) a true lignitic stratum. A similar stratum, perhaps the same, reappears near the ridge between kilometers 54.50 and 55.50. It contains here melanites (?) and a small congeries, but the fossiliferous limestones of kilometer 49 are faulted. Mr. Cayeux found only one foraminiferous specimen in the strata below the lignitic layer.

These facts can be summarized as follows:

On the Pacific slope the Gamboa rock supports a formation which occupies the place of the Vamos-Vamos strata, but has only the richness in volcanic elements in common with them. This formation, composed of bituminous schists and grit, has a more coast-like appearance, accentuated by the abundance of terrestrial plants, and is even partly marine, as is shown by the presence of a congerie. It grows in thickness as it recedes from the anticlinal central arch, and is overlaid by Miocene limestone, where another lignitic layer is interjected.

Therefore, from what precedes, there are no sufficient reasons to classify the Culebra system under the Aquitanian. This might be a local stratum of the lower Miocene; but the outcroppings of the calcareous strata, worked in former times to provide limestone for kilns near the station of Emperador, render this last assumption improbable.

These calcareous layers were examined by Mr. Hill. He describes them as situated at about 3 kilometers (1.86 mi.) from the northwest side of the top of the Culebra, near Emperador station, and forming two small outcroppings near a ravine among the superficial red clays. At the distance of about 20 meters (65.61 ft.) farther down appears the volcanic rock, and 100 meters (328 ft.) to the north, in the railroad cut, we find stratified clay of the Culebra system.

Mr. Bagg, who examined a cut of this limestone, has found nummulites, an orbitoïde, and other Foraminifera (*Cristellaria*, *Rotalia*, *Nodosaria*). The nummulites are the predominating types. This association of the nummulites and orbitoïdes reminds us of the Bohio rock, and it is very probable that we have here an Aquitanian limestone; at all events it is not Miocene. Mr. Hill says that we can not see the stratigraphic relation of the calcareous material with the neighboring formations, but it is his impression that it is a lenticular bank of limestone, included in the Culebra system. This opinion is confirmed by the results of the Riehier boring (km. 53) of the old company. This boring, situated immediately opposite, at about 500 meters (1,640 ft.) from the preceding outcrop, shows a very hard, compact layer of limestone only 5 meters (16.40 ft.) thick, intercalated between bituminous schists and grits which are not shown by the adjacent borings. It is presumably the same limestone, whose position would thus be determined without ambiguity and would establish the Aquitanian age of the entire Culebra system.

It must be remarked that there is, moreover, a calcareous outcrop in the railroad cut at the station of Emperador and another at Las Cascadas (note of Canelle). But this limestone is quite different; it is lumachel with *Ostrea* and *Pecten*, containing with polypiers the *Pecten subpleuronectes*, identical with the limestone of kilometer 49, which is doubtless connected by a series of continuous outcroppings. We shall later consider the proofs of the Miocene age of this limestone when we shall speak of the "mollasse" (Fr.) of Alhajuela.

It remains to mention in the system of the Culebra the intercalation of tuffs and contemporaneous andesitic flows. One of these flows has been followed by the drift gallery at level 41; similar rocks have been found in several shafts at levels which do not permit us to consider them as one flow. The microscopic examination shows besides, independently of the presence of tuffs, that it can not be an intruding layer.

Pacific slope.—Beyond the large cut the lignitic system sinks and disappears below the sea level. The knowledge of this part comes only from the old canal work and the numerous intrusions of volcanic rocks, perhaps accompanied by faults which render their interpretation considerably obscure. However, two important facts are clearly shown: First, the reappearance of the limestone of kilometer 49 with the same fossils at kilometer 59.40 at the projected location of the lock of Pedro Miguel. This limestone seems to be intercalated in the upper part of the lignitic grit, and contains oyster shells, the *Pecten subpleuronectes*, and rounded orbitoïdes. The borings permit us to follow it up as far as kilometer 60.30; they show it again at kilometers

62 and 63, then it disappears to give place to gray trachytic tuffs, which increase more and more as they approach the coast. The second point is the incontestable superposition of the calcareous tuffs, discovered in the borings of kilometers 62 and 64.10. The trachytic tuffs are therefore more recent than at least one part of the limestone containing *Pecten subpleuronectes*, i. e., than the base of the lower Miocene. They are associated with trachytic rocks (Cerro Ancon, near Panama), and are certainly of marine origin; for. in the identical rock of Barbacoas, Mr. Cayeux found a foraminiferous specimen and Mr. Boutan brought from the Panama coast a small gastropod (cerite?) in a specimen full of Foraminifera and associated with trachytic tuffs.

We have said that Mr. Hill considered the trachytic tuffs as very ancient and presumably Cretaceous. The other observers (Wagner and Boutan) had only indicated that these tuffs must be previous to basic eruptions. The first of these suppositions can not be sustained any longer. As to the second opinion, it is only exact if we distinguish, as we shall, two series of basic eruptions, the tuffs being, from what precedes, certainly of a later age than the Gamboa rock.

The stratigraphic position of the trachytic tuffs and their marine origin leads us to see in them the representative of the argillaceous series of Monkey Hill, where strata of tuffaceous appearance are intercalated, rich in crystal, and containing especially orthoclase. This result is important, because it shows us the Isthmus as formed by a symmetrical bulging, whose summit does not coincide with the line of the ridge, but is situated about in the middle of the Isthmus. The center of the bulging is formed by the volcanic breccia (ancient eruptive series), and on both sides strata of the same age sink symmetrically toward the two oceans. Only, on the Atlantic side, the series is certainly marine and without volcanic intercalations; on the Pacific side it is partly marine and rich in eruptive intercalations.

According to the data collected by Mr. Wagner it seems probable that the breccia of Gamboa reappears in the islands of the bay of Panama. That would lead us to suppose that the central bulging of the Isthmus has not had, since the Oligocene epoch, the importance which the difference of composition of the two slopes would at first tend to give it, and that the true cause of the difference is the existence of a coast line in the southeast. There is, perhaps, here a very interesting consideration reserved for the history of the formations of the Isthmus.

Central part—Plateau of Alhajuela.—It remains now to consider the central part. The canal cut shows only a mighty development of the breccia of Gamboa, with a fragment of lignitic schists still preserved at its surface, near Matachin. But in the railroad cut we find trachytic tuffs superposed on the breccia, and these tuffs seem to be inseparable from those which are shown near the bridge of Barbacoas and are identical with those of Panama. The central part presents here the Gamboa breccia, directly covered by trachytic tuffs.

If we proceed toward the east, following the valley of the Chagres, we find at first, in the river bed near Las Cruces, an outcropping of compact limestone with polypiers, which represents perhaps the same Aquitanian level as at Emperador. But farther up the river the bed of the Chagres and the entire plateau as far as Alhajuela are occupied by compact and well-stratified calcareous sandstone, where we again find the fauna of kilometer 49. There is, first, the *Pecten subpleuronectes*, then the *Turritella tornata;* there is also a large Clypeaster, of a type which is different from the Aquitanian type of Schio; there are also the large Bivalves, among them the *Mytilus michelini*. The rock is quite similar to that of our European "mollasse" (Fr.), and the character of the fauna is very similar to that of the strata of Carry, near Marseille (Upper Oligocene changing into the Miocene). The Clypeaster and the Turritella connect rather the whole with the Miocene, which is, however, only an insignificant difference and a question without importance considering the continuity of the deposits. The microscopic analysis shows in much of the volcanic débris (without recognizable orthoclase) bryozoaires and numerous Foraminifera, among them a globigerine.

In ascending beyond Alhajuela we find, according to Mr. Canelle, white limestone, determined by Mr. Boutan as partly identical with the rock of Peña Blanca and containing here and there large orbitoïdes. This limestone sinks gradually and very regularly under the preceding series.

The result of this disposition is that the axis of the central arch, as is sufficiently well shown by the topography, must take an eastern or east-northeastern direction toward the Altos de Maria Enrique, where Wagner reports knolls of granite. On the west side the development of the trachytic tuffs in the plain of Palanquilla and the valley of the Rio Grande, and, moreover, the continuation of the lignitic strata near the dividing ridge in the valley of the Rio de los Indos, seem to indicate that the bulging is continued between the two systems; that is to say, sensibly in the same direction, following a line which almost coincides with the average course of the Chagres between Las Cruces and Baila Monos. The centers of eruption of the Oligocene period, entirely basic, would then be localized on the south slope. The trachytic centers of the Miocene epoch, although more abundant on the same slope (Cerro Ancon, Cerro Comboy) would also appear on the north slope (plain of Palanquilla), but very near the top of the bulging.

Later eruptions—Dividing ridge.—The sedimentary series of the Isthmus ends with the formations above described, but eruptions continued after the deposition of the lower Miocene. These later eruptions constitute, at least near the canal, the summit of the line of the present ridge. They are, again, basic eruptions of andesitic nature. As far as we know they are also peculiar to the south slope; at least we have knowledge on the other slope of only one cinerite of basic rock, superposed on trachytic tuff, and cropping out on the banks of the Rio Gigante.

We can only fix the lower limit for the age of these rocks; they traverse in veins the lower Miocene upon which their flows are superposed. But it may be important to say that they have not the least connection with the recent volcanic series of Costa Rica, Nicaragua, and Guatemala, where the existing volcanoes are only feeble successors of the ancient ones. All observers, and especially Mr. Hill, are explicit on this point. The earthquake disturbances of the region are closely associated with the volcanic eruptions; it is, therefore, important to know that volcanic activity has long ceased near the Panama route.

Though we can not obtain precise facts as to the epoch at which this activity ceased, it seems to have very likely occurred during the Miocene period. Mr. Hill has observed, in confirmation of the same opinion, that the upper clays of the Monkey Hill do not contain crystals in débris. This proof is not sufficient, even supposing that this absence is well established, but we can say that the basic cinerite of the banks of the Rio Grande appears closely associated with the upper part of the trachytic tuffs, and that the flows of the Cerro Culebra and of the banks of the Rio Chilibre seem to overlie almost conformably the Miocene layers. It appears, therefore, that no extensive denudations occurred during the interval, which would not be easy to explain in a region adjacent to the summit of the anticlinal bulging if this bulging and the corresponding emersion had taken place long before the eruption.

The numerous veins which traverse the lignitic system are probably the dikes through which these rocks made their way. The fact is at least proven for the veins which Mr. Zürcher observed in the large cut. Their composition is indeed identical with that of the rocks of the Cerro Culebra. It is true that we find in the conglomerate of Bohio lapilli of an analogous rock, but near kilometer 54, that is to say, under Cerro Culebra, the dike of a composition similar to that of the cerro differs completely from the neighboring flows, which are intercalated in the lignitic layers. At all events, we must keep well in mind that these subsequent eruptions of volcanic rocks have in no way dislocated the strata through which they broke. From this fact we have no need to fear the upheavals and disturbances of the strata, to which the surveying commission of 1884 deemed it necessary to call attention, owing to the favorable arrangement of the strata.

The later eruptions are of considerable importance as regards the topography, since they form, at least to a great part, the top layers. What we see to-day are the remains of their layers, which have certainly had a much greater extent. The preservation of these rocks following the line of the actual ridge is explained quite naturally, because this line follows the edge of the central bulging and corresponds with the relatively abrupt dipping of the layers which happens at this point. In the same manner the Dammartin and Villers-Cotterets hills, in the Paris basin, are lined up on the edge of very slight bulgings of which they mark the general direction. We must conclude from this observation that the flows are anterior to the later movements

which raised the strata of the Isthmus. Furthermore, we find, according to Mr. Hill, on the Atlantic coast of Costa Rica, proof that these movements are anterior to the Pliocene formation. We have here, therefore, a confirmation of the fact that these rocks belong to the Miocene period.

Superficial red clays.—We have now to mention a formation which has no special age, but which is, however, the best known and best shown on the Isthmus, and one which at once impresses itself on our mind when we speak of the great cut; we mean the red clays. These clays, peculiar to the tropical climates, are the result of a disintegration of the strata by atmospheric influence. When this disintegration is complete it leaves a red, ferruginous, unstratified mud; but it contains all the intermediate degrees, and the incipient decomposition may have left certain characteristics of the strata, and particularly the division into well-defined banks. That is to say, we are in the presence of an apparently sedimentary system with lithologic characteristics and seemingly corresponding to a special formation. This notably occurs in the upper part of the great cut, where the red clays are still frequently well stratified. They resemble very much a more special sedimentary system which places all the others in discomformity, as we distinguish there more layers with intercalated breccias. They represent, nevertheless, a species of more or less advanced alteration.

When there exists in the series an impermeable clay bed it is natural that the alteration stops at this layer. The series of red clays often rests on a clay bank which would, especially in the case of abundant infiltration, favor sliding. The danger is especially great when the slope of the layer lies toward the cut. In that case a feeble shock, or even the weight of the material alone, may be sufficient to make these clays slide on their inclined and lubricated bed; and if their mass is considerable it is believed that, when once set in motion, nothing could stop it. We have lately seen, though in other regions but under similar conditions, an impressive instance of these phenomena in the sliding of the Gouffre, on the banks of the Gardon River, in the Alais basin. We have seen, even in Panama, an equally famous case, although on a much more reduced scale, in the landslide of Cucaracha. The precautions to be taken in order to prevent similar accidents are well known and have already been applied with success.

Besides we may add that the arrest of decomposition at an impermeable layer which serves as a base for the red clays is more theoretical than real. Indeed, there is rarely a distinct line of demarcation; more often the clays carry with them their substratum on all intermediary passages. In that case a movement of the whole is not to be feared, and the danger would be confined to some local landslides. At Cucaracha the level of the clays was reached long ago, and the great width given to the old excavation is already a guaranty. It is, however, advisable, because of the slope mentioned and the thickness of the clays, to reenforce and rather to exaggerate, on this point, the measures to prevent sliding.

Alterations of the strata in depth.—Here is the place to speak of another mode of alteration, less apparent and probably also due to special conditions of the climate. The clayey bed which stops the deep changes of the terrain does not entirely prevent the circulation of the waters in the deep strata, and from this circulation a very curious and special phenomenon results, which has been made evident by cutting thin slices for microscopic examination. Rocks apparently compact and solid disintegrate rapidly when wet. After an immersion of a few minutes a slight pressure, even of the finger, crumbles them, and this has even occurred in the case of an eruptive rock. To be able to make the thin slices it was necessary to immerse them in oil and not in water. This fact is explained, to a certain point, when we examine these cuts under the microscope. All of these rocks are traversed by argillaceous filaments which feebly depolarize light and which form with crystalline residues the body of the rock. This clay, according to Mr. Cayeux, differs considerably in appearance from that which he had occasion to examine in the rocks of our country, and appears frequently to be the product of decomposition, although very difficult to distinguish from true argillaceous deposits shown in other samples. In the eruptive rocks it is the vitreous particles that seem to have undergone this decomposition.

Whatever may be the chemical cause, the fact is certain. Rocks apparently solid and freshly taken from deep shafts possess only an unstable cohesion, and it requires only a slight effort to

break them up. They separate like marl or granulate like sand, and from the practical point of view it might appear that this phenomenon must cause unfavorable conditions in the cuts. But we may reply that experience has demonstrated that deep excavations, left exposed for more than two years to weather, have stood perfectly without revetment. It would seem that the unstable cohesion mentioned above is more stable in mass than in small fragments, and that the sides of a cut do not act like an isolated fragment. Indeed, this is a question which we should not neglect, especially with regard to the line of the canal, and which may tend to increase the anticipated importance of substantial revetments. Perhaps we may be able to establish a connection between this condition and the rather curious fact that terraces of the great cut seem, during the later work, to stand better the steeper the slopes are. They stand better, at least momentarily, with a steeper slope because they are more massive and better sustained; and to this we must evidently add that the surface exposed to the action of the water and consequently the influence of this action are so much less as the slope is steeper.

Alluvial soils and Quaternary phenomena.—In conclusion we must add a word on the Quaternary formations which occur in the great alluvial plains where the valley of the Chagres broadens. They have, unfortunately, a thickness sufficiently great in the region of the projected dams to prevent us from reaching the subjacent rock for the purpose of getting fonndations. We know very little about this subject. However, Mr. Zürcher was able to ascertain the existence of an old "terrasse" near Bohio, composed of gray, compact, and sandy clay, below which the borings have struck a thick bed of gravel mixed with argillaceous sand. The continuity and the homogeneousness of this clay bed have been established for a considerable area. This layer secures, therefore, a stable base for a great earthen dam. But it is difficult to draw, solely from the existence of this "terrasse," any precise conclusion concerning the history of the formation of the valley.

From the view point of recent earth movements Mr. Hill observed that near the mouth of the Chagres a part of the clays of the plain are of marine formation. But we can not draw any conclusion from this, since we are here almost at the actual level of the sea. Mr. Hill observes, besides, the traces of an ancient plain of marine denudation (ancient base level) on the top of Monkey Hill and the Mindi Hills. This indicates a rise, relatively recent, but of an undetermined age. The absence of the Pliocene along the Atlantic coast, except at one point on the coast of Costa Rica, shows, on the other hand, that the sea at this epoch reached less far than at present. The indications are, therefore, opposed to this theory, and only denote an alternation of rising and sinking movements without permitting us to draw any precise conclusion. On the Pacific slope the bay of Panama, with its islands standing isolated, seems to show a more marked tendency to submersion, and the impression is confirmed by the examination of the contours, which again seems to suggest an ancient submerged valley.

Résumé—Cross section.—The central bulging is formed by eruptive Oligocene rocks. In a kind of depression of the bulging ridge are lodged the calcareous sandstones of Alhajuela and the trachytic tuffs. On the two slopes the eruptive breccias pass into the conglomerates, where strata containing nummulites are intercalated; it is the Tongrian or the lower Aquitanian. Then, on the Atlantic side follow, first with a rather steep slope, afterwards in undulations, and finally horizontally, the successive strata of a continuous sedimentary series—calcareous rocks with orbitoïdes, the glauconeous layers of Vamos, the sandstones of Gatun, which are equivalent to the "mollasse" (Fr.) of Alhajuela, and the clays of Monkey Hill. On the Pacific side is reproduced almost symmetrically the same characteristics of a rather abrupt slope, followed by more or less marked undulations; but the marine series is replaced by a partly marine series with lignites, where the tuffs and the eruptive flows play an important part. The most recent basic rocks, which are presumably Miocene, fill a series of vertical chimneys between Pedro Miguel and the Culebra, and show their preserved expanse only on the Pacific edge of the bulging, along the more abrupt slope of the formation.

DESCRIPTION AND MICROSCOPIC DIAGNOSIS OF THE ROCKS.

It remains now for us to consider some of the more exact details of the different formations which will be met in digging the canal.

Gamboa breccia.—The breccia is extremely hard, which fact will make the work much more difficult and slower than in other formations. It is therefore a favorable circumstance that the topographic crust does not coincide with the axis of the convexity. We may say that not more than one-tenth of the canal cut has to be dug through the Gamboa rock.

We see from the description of Mr. Boutan that the Gamboa rock presents numerous varieties, from the massive eruptive rock to the conglomerate, or to the breccia containing great blocks whose volume may be several meters. Mr. Boutan has, besides, well established the fact that except on the shores, and notwithstanding variations, the concretion is of volcanic origin (pyroxene in crystals, labradorite, and oxide of iron) and of indisputable eruptive nature. We give here the diagnosis of Mr. Termier concerning a specimen from Bohio, near the canal, and concerning a specimen from the quarry of Bohio:

Gamboa rock.—Volcanic tuff, lapilli of various andesites, rich in augite and feldspar, some containing much iron and mostly vitreous (they contain a little olivine); others are microlitic and magnesian (a decomposed concretion which has become green). The feldspar, often in streaks, passes from bytownite to anorthite.

Besides these andesitic lapilli there are numerous débris of augite and feldspar crystals, coming from analogous rocks.

Cement composed of a green isotropic matter (serpentine). In this dark-green substance there are here and there lighter places, greenish-yellow, composed of tenuous parallel or radiating fibers, ending longitudinally and having about double the refracting power of amphibole. The augite of the lapilli and of the débris is very much altered and turns into the very isotropic green matter which forms the cement of the tuff. There is no substance present which is not of eruptive origin. Here and there calcite mixed with the cement or found in the cracks.

Rock from the quarry of Bohio (cement of large blocks).—Eruptive tuff, lapilli of various andesites, generally finely microlitic. One of these andesites resembles very much those of Cerro Culebra. The other contains large crystals of oxide of iron, of augite, and of basic feldspar (from 60 to 80 per cent of anorthite) in a holocrystalline concretion of very fine grains of labradorite, augite, and oxide of iron. All of these andesites are always very feldsparic, and their feldspar is always very basic (anorthite or bytownite), sometimes markedly zoned.

With these lapilli of andesites there are numerous frequently angular débris of feldspar and augite. The cement is a kind of isotropic serpentine, formed at the expense of the augite or the concretion of the lapilli. There are no grains of sand; all of the substances are of volcanic origin.

This tuff is very analogous to that of Gamboa, though the lapilli are not quite the same. Those which predominate in the tuff of Gamboa are of a more vitreous rock, more charged with oxide of iron. But the feldspars are identical and the chemical composition of the two rocks should vary but little.

It must be mentioned that first Mr. Wagner and after him Mr. Boutan determined two varieties of breccia, one with basic fragments, which has been described above, the other with fragments containing more acid, the second appearing to be inferior to the first. We have had the chance neither to see nor to study this second variety.

Near Emperador and Las Cascadas (borings at kms. 49.50 and 48.38) the old cut shows, intercalated in the clayey rocks (i. e., in the eruptive rock, so far as it seems permissible to interpret the adopted terms), violet or greenish and very hard jaspers. Pieces of them are found on the surface, embedded in the clay which overlies the Gamboa rock. Large pebbles of the same kind are also found in the alluvial soil of the Rio Grande. These specimens show, under the microscope, an aggregation of quartz more or less coarsely crystallized, but always without a trace of fossils. Some are zoned; the parallel and differently colored bands correspond only to a difference in the size of the quartz crystals. It is at present difficult to form an opinion on the origin of these jaspers.

The conglomerates, which are markedly developed and very visible at Bohio, are remarkable on account of their different natures and the large size of the included elements, of which only a part is rounded. It has not been doubted by any of the observers which have succeeded each other that these included elements were transported from their beds by water, but it is difficult to explain with precision the mode of formation and the origin of these strange elements.

Among the pebbles of the conglomerate Mr. Termier examined and described a basic microdiorite, two amphibole andesites, an augite andesite, and other more or less vitreous andesites. The variety of the elements seems, therefore, to be very great. The microdiorite especially has an appearance of freshness and of age which distinguishes it from the other rocks of the country. The following is a description of it by Mr. Termier:

Basic microdiorite.—Large crystals of horneblende and large crystals of a zoned feldspar, passing usually from andesite to the anorthite, sometimes from oligoclase to anorthite. Generally the kernel is more basic than the outer part, but sometimes the contrary is true. In all probability the zonage has been exaggerated by the metasomatism. Kernels altered, outer parts limpid.

The concretion is a mosaic of very small feldspar, sometimes zoned, almost always very basic. In the interstices of this mosaic are small laminas of chlorite replacing probably a streak of black mica. The rock passes into the lamprophyres. It is without doubt a relatively deep form of the amphibolic andesites.

This last remark, attributing the varying appearance of the rock not to difference of age but to a difference of depth, suggests the idea that the supposition of its having been transported by water may be wrong and that we have before us fragments which have been thrown off—torn, broken, or smoothed off, by friction in a volcanic crater.

SYSTEM OF THE BITUMINOUS SCHISTS (CLAYS AND TUFFS OF CULEBRA).

The system of lignitiferous strata, with its breccias and intercalated flows, forms the great mass of the terrain cut by the excavations at Emperador and La Culebra. We have collected the following information concerning it: The intercalations of volcanic rock in the breccia ought to be much more numerous, even if the first layer of breccia is not volcanic. With regard to a specimen obtained at kilometer 48.10, between levels 19 and 20, Mr. Termier gives the following diagnosis:

A black, spongy rock, almost entirely formed of a brownish glass; here and there crystals of andesine corroded by the surrounding iron. The walls of the vacuols are lined with small crystals of quartz. The rock is a vitreous, scoriaceous andesite subsequently silicified.

The relative acidity of the feldspar is noteworthy. The greater part of the andesites of this region are bytownitic or anorthitic.

At the same point at level 20 the rock belongs to a vitreous breccia-like flow, which is thus described:

Vitreous breccia-like flow.—Pebbles of a black augitic andesite, rich in Fe_3O_4, analogous if not identical with that of pebble from breccia of Bohio. Isolated débris of feldspar and augite, seemingly coming from this same andesite. Some of these feldspar débris are corroded and smoothed off, as if the surrounding matter had dissolved them partly. This surrounding matter is a brownish glass, full of formerly gaseous bubbles. These cavities are now filled with zeoliths or fibrous amphibole. In each cavity there is a thin lining of another fibrous refracting substance, like glass, of palagonite.

A specimen of the breccia of the second layer, below the small falls of Obispo, was examined by Mr. Cayeux. It is a breccia with a dirty yellow cement, unctuous to the touch. It contains numerous pieces of andesite. The cement is very phylliteous in places.

At all events, on the other side of the dike which causes the falls (rocks not examined) we find above this latter breccia a purely sedimentary series consisting of small quantities of schists and sandstones overlaid by the calcareous lamina of kilometer 49, with *Pecten subpleuronectes*, and by the lignitic layer. This whole structure thus forms a basin in the breccia of a length of 500 to 600 meters (1,640 to 1,968 ft.). The result of this seems to be that the purely sedimentary system has here very little thickness, about 30 meters (98 ft.), of which scarcely a few meters are bituminous schists, and that therefore, from what we have seen, the thickness increases considerably in passing from the bulging to the Pacific.

Between kilometers 50 and 52 there is a double bulging of the eruptive substratum, which causes the Gamboa rock to rise in two places near level 60. It is this double bulging which presents for the excavation at Emperador a terrain which is much harder to work than that of the excavation of La Culebra. On this whole space the eruptive rock is overlaid by breccias, among which there are perhaps a few sedimentary pudding stones, but a great part of which seems at least of mixed origin. Thus at kilometer 50.64, level 40, we find a hard grayish-green rock,

showing a few fresh and gray-spotted feldspars. The appearance shows nothing of a sedimentary nature. At kilometer 51, level 40, it is a dark-gray rock showing a few vitreous feldspars and fragments of volcanic rocks. Under the microscope it consists essentially of a concretion doubling up in a streak of chlorite, continuous or not, mixed, with an amorphous matter predominating. We see, with several streaks of calcite very much cut up, a few pieces of decomposed andesite and a very few very rare basic plagioclastic feldspars. Mr. Cayeux takes it for a much-altered concretion of tuff.

At kilometer 51.50, level 38, we find a breccia of coarse elements which under the microscope are seen to be composed essentially of pieces of andesite of all sizes, with large basic feldspars. There are besides quartz and secondary calcite in vacuoles and some nidi of epidote. This breccia may also belong to the Gamboa system, and shows the intimate connection of the two series. Throughout this whole space, that is to say between kilometers 50 and 52, the breccia is covered by red clays resulting from an incomplete decomposition, which still permits us to distinguish the stratification as well as the banks of breccia and a flow of intercalated volcanic rock. The whole is pierced by two large veins (not examined) which rise to the height of the excavation, with a marked tendency to spread out above (kms. 50.18 and 50.65). The red clays of kilometer 51 have recently slid to some extent.

Before we leave this section it is well to mention the diagnosis of the two rocks attributed in the cut to the upper part of the Gamboa series (km. 50.72, level 45, and km. 50.776). The first is a vacuolar andesite, of which Mr. Termier gives the following description:

Vacuolar andesite.—A semivitreous, semimicrolitic rock. The microlites consist of very small tablets of bytownite. Here and there a few small crystals of the same feldspar and some crystals of a magnesian mineral entirely transformed into calcite. The structure is somewhat stream-like.

The microlites range themselves tangentically around the border of the vacuoles, where a margin of oxide of iron has formed. The vacuoles themselves correspond to the vitreous cavities, in which there are small particles of the surrounding microlitic rock. Of the vitreous cavity little glass is left; the remainder was transformed into a mixture of chlorite and quartz or into a spherolitic aggregation of amphibole. These secondary formations are easily detached, hence the vacuoles, which replace many of the old cavities. This specimen seems to come from a flow.

The rock of kilometer 50.776 is a dark brick-red rock with green spots. Even the color indicates a more advanced decomposition. Under the microscope we see streaks characterized by greenish sections of chlorite, of a coarsely circular form or clearly polygonal, embedded or not in a microlitic concretion, according to the state of alteration of the rock. One of the polygonal sections resembles that of leucite. There are rarely pieces of andesite. The concretion is reddish and decomposes into a fine chloritic mixture and amorphous clayey matter.

From this description we see that, as far as kilometer 52, outside of the small basin of kilometer 49, we have not very clear proof of the existence of a purely sedimentary series. The red clays are too much decomposed and the eruptive element plays too great a part in the breccias to enable us to connect with certainty the whole or a part of this series with the terrains encountered farther south. We must remember that the nummulitic limestone crops out in this region a little to the east of Emperador station, in the midst of red clays, and very little above the eruptive rocks which are found at the bottom of the valleys.

Cut at Culebra.—At kilometer 51.84 the Gamboa rock disappears and sinks definitively in depth with the stratum of breccia which we have followed up so far. If there exists no fault, and nothing indicates that there is one, it would be an indication that the breccias are intimately connected with the Gamboa rock. There are still in the south some intercalated breccias, but nothing reminds us of their enormous development in the north.

The mass which extends to the extremity of the cut is in its whole make-up purely sedimentary, composed of bituminous schists of more or less argillaceous sandstones, which are crowned by a bank of lignites. The strata are about horizontal, except at the edge of the eruptive substratum on which they rest, but form, however, a double undulation, which, at the extremity of the cut, bring them definitively to a lower level. The summit of the system is still seen at site 15 near Pedro Miguel (overlaid by the same limestone as at km. 49), and then sinks below the level of the sea. Besides the distinct undulations we must take notice toward kilometer 55 of a notable inclination of the strata toward the southwest, due probably to a slight transverse undulation.

This inclination creates, from the point of view of the stability of the layer of red clay on the left bank, unfavorable conditions that have already caused the sliding at Cucaracha. This sliding has long since stopped and the engineers do not fear its recurrence. We must, however, repeat that it will be prudent to rather exaggerate the preventive measures.

As an example of the composition of the sandstone formations, we cite the diagnosis from kilometer 53.534:

Sandstone, nearly half of which is composed of quartz; aggregations of quartz are frequent; there are fragments of very much altered eruptive rocks, more or less greenish; some pieces of andesite and isolated feldspars; green grains with rounded contours which might be glauconic; the cement is composed of an argillaceous matter.

Comparing it with diagnosis from kilometer 54.20:

Fine level sandstone; grains somewhat mixed with quartz; angular débris of feldspar and augite; grains of limonite and chlorite slightly rounded. Argillaceous and ferruginous cement, containing undeterminable crystals; some lapilli of volcanic rocks, much altered and scarcely recognizable.

As an example of the schist formations we also cite a few diagnoses:

Kilometer 54.680.—Gray coherent clay. Under the microscope is seen a sedimentary clay, partly crystalline, containing small pieces of quartz and pieces of altered feldspar.

Kilometer 55.465.—Greenish-gray rock studded with green grains. It is a very crystalline clay, containing numerous glauconic grains, of which one includes several organic débris, among which one is foraminiferous. Clastic quartz very rare; pieces of altered feldspars; a few fragments of glass and of a microlitic much-altered rock.

Kilometer 55.645.—Maroon-gray rock having the appearance of a desiccated clay. It is a very fine clay, composed of an intimate mixture of amorphous matter and fine crystalline particles. Small veins and streaks of a dirty yellow, fibrous, doubly refracting matter. Occasionally small grains of clastic quatz.

Kilometer 55.513, level 41.—Clay. Lapilli of small pebbles of basic rock, much altered, cemented with a ferruginous clay, which itself seems to come from the decomposition of similar materials; occasional grains of quartz.

Finally a white clay, found on top of the lignitic layer at the base of the altered series, gave to Mr. Cayeux the following composition:

White clay, very coherent.—Under the microscope is shown an extremely fine clay, the greater part amorphous, with streaks and small particles of well-rounded calcite. There are a few pieces of clastic quartz.

We must observe that all of the preceding diagnoses apply to specimens from the upper part of the cut, obtained near flows of volcanic rocks. From a lot recently forwarded we have been able to examine pieces of bituminous schists coming from deeper levels cut by the test borings. The proportion of volcanic fragments is much smaller and the bituminous matter seems, under the microscope, to assume the form of black patches. Foraminifera are abundant in these cores. Mr. Cayeux, as we have said, has recognized sections of textularias and globigerinæ.

Toward the upper part of the cut we find an intercalated layer of eruptive rock, which from the points determined in different places appeared to us slightly oblique to the strata, and which we at first attributed to an intruding layer. It is not so; it is a flow accompanied everywhere by incontestable tuffs. The obliquity of its bed is without doubt due to the fact that there are several flows of slightly different levels. We give here the diagnosis of the rock (km. 34.30, level 70):

Gray andesite.—Crystals of labradorite slightly zoned, containing about 65 to 70 per cent anorthite. "Pâte fluidale (Fr.) to a great part still vitreous, but which must have been originally entirely vitreous, and which has been partially devitrified." The product of this devitrification seems to be a feldspar probably more acid than that of the large crystals.

A few crystals of apatite; a few grains of Fe_3O_4. The absence of magnesian minerals seems complete. This specimen seems to come from a true flow. The rock is, considering the region, of remarkable acidity. None of the other 31 specimens examined show any resemblance to it. The veined rock obtained at a point very near the former is entirely different.

With regard to the tuffs which accompany this flow there are several diagnoses which are not of doubtful character:

Kilometer 54.40, level 72.—Tuff or cinerite. Lapilli of various eruptive rocks, considerably decomposed; vitreous débris; numerous débris of crystals, feldspar, and augite; clayey cement.

Kilometer 54.58.—Grayish-green rock showing some pieces of vitreous feldspar. Under the microscope we see numerous débris of microlitic rocks with an entirely crystalline or noncrystalline mass; we find several pieces of andesite. The feldspars of these andesites are more often small microlites and occasionally elements of large size, which make of the rock a kind of diabase. There are large isolated pieces of basic feldspar, generally fragmentary;

vitreous débris are also present. The cement is a vitreous product containing in places bodies which are difficult to determine, visible under feeble magnifying power, and which I consider as crystallites of large size. It is really an intimate mixture of a predominating amorphous matter and of fine crystalline particles, resulting from the partial devitrification of the amorphous matter. The rock is tuff.

It is interesting to compare with these contemporaneous elements the veined rock behind kilometer 54.41. It is, according to Mr. Termier, a black augitic andesite, with very fine grains, holocrystalline, semiophitic, resembling certain diabases. The diagnosis is as follows:

Small tablets of anorthite, sometimes arranged in a vague stream-like texture, cemented by shapeless crystals of augite or by a brownish isotropic matter, which seems to come from the decomposition of the augite. Magnetite is very abundant.

The rock is, as I have said, almost identical with that which forms the Cerro Culebra and whose diagnosis is as follows:

Augitic andesite.—Disarranged small tablets of anorthite, sometimes zoned and thus retrograding toward the bytownite. In the interstices are grains and pockets of augite and much brownish glass partly devitrified. Consolidation seems to have taken place very rapidly. Many small grains of magnetite are present.

Only one of the veins piercing the lignitiferous system vertically has been examined. But there are many others, notably on the Pacific slope the large dikes of Paraiso and that of Pedro Miguel. It is not certain, and not even probable, that all these dikes have the same composition; and if they have (like the Cerro Culebra) given passage to the rocky eruption of the cerros we can not wonder that the latter, though belonging with certainty to the same geologic series, have not everywhere the same composition. Thus a specimen brought over by Mr. Zürcher, and coming from an upper layer of Miocene sandstone in the upper valley of the Chilibre, gave the following diagnosis:

Micaceous andesite.—Large crystals of andesine, sometimes a little zoned; crystals of augite, and black mica (the latter much altered). Mass to a great extent vitreous, in which are isolated microlites of andesine and others of black mica, the latter badly formed and partly decomposed.

This rock has a far different composition from that of Cerro Culebra. It is certainly much less basic.

Section of the Pacific slope—Trachytic tuffs.—The last section of the canal, that of the Pacific slope, needs much less study. There are no more deep cuts. We stated that after having traversed an intermediary region, where the lignitiferous system again appears, cut by large dikes and overlaid by fossiliferous limestone (km. 49), we pass into that extended part of the plain of the Rio Grande which under the alluvial soil seems to be composed entirely of trachytic tuffs.

We give here two diagnoses of these tuffs:

Cinerite of vitrophyry.—Débris of brownish or greenish glass with numerous small cavities of an oblong form. Various crystals, feldspar, and augite, partly destroyed. Clayey cement of a light-brown color, with very large patches of a light-green color. This cement is cryptocrystalline. The small cavities are filled with various secondary minerals, among others a cleavable zeolite, feebly birefracting, and with small spherolitic tufts of a very dark-green material, probably amphibole.

Cinerite of vitrophyry.—Needles of a brownish glass, generally curved; shapeless débris of a violaceous glass; crystals of mica and vitrified feldspar, débris of variable feldspars, oligoclasic albite, or basic feldspars, the whole embedded in an amorphous cement in which very fine crystalline fibers of an indeterminable substance can be distinguished; a great number of small cavities.

With these cinerites (rhyolitic tuffs of Mr. Hill) are associated points and knolls of trachyte, as at Cerro Ancon:

1. Trachyte.—Holocrystalline rock which contains only thinly scattered pieces of sanidine with albite and Carlsbad macles. The mass is a confusion of very fine shapeless lamellæ of an acid feldspar, probably anorthose (occasionally macles); of small needles or small grains of a greenish-yellow mineral, feebly polychroic, doubly refracting (probably altered mica), and of small and thinly scattered grains of magnetite.

Finally, though the cut of the canal does not meet with them, we call attention to the fact that the plain of Palanquilla, opposite Barbacoas and Frijoles, is composed of the same tuffs with similar trachytic points. We give here the diagnoses of these rocks:

Vitrophyrous cinerite, with traces of organisms.—Vitreous débris in various forms, some angular, some perfectly rounded, frequently as curved needles. This glass has a clear light-golden color. It contains here and there gaseous

inclusions, crystalline or vitreous refracting corpuscles. With this vitreous débris there are found, according to Mr. Cayeux, small bodies of organic origin, traces of Foraminifera, and spiculæ of sponges. These spiculæ are partly amorphous (opal) and partly crystalized (chalcedony).

This very fine dust (the largest particles of the débris are one-third mm. in diameter) is cemented together by a brown isotropic matter, considerably charged with oxide of iron, doubtless a vitrocrystalline cinder transformed into clay by metamorphosis. Numerous vacant spaces.

2. Trachyte.—The same rock as No. 1, but more altered, at least as regards the magnesian mineral. Crystals of sanidine of a considerable size interspersed with albite; a holocrystalline mass of anorthosis with disarranged streaks of a brown isotropic or almost isotropic substance, which is the result of the decomposition of a ferromagnesian mineral (probably black mica); a little magnetite and oligist.

The anorthose occurs frequently in flattened crystals, clearly formed, while in specimen 1 it generally occurs in shapeless lamellæ.

The banks of the Rio Gigante are formed, according to the only specimen we have from them, of a basic cinerite, probably superposed on trachytic tuffs. We give here the diagnosis:

Cinerite of basic rock.—Fine sand composed of crystals and zoned basic feldspar, of augite crystals, of small lapilli of a much altered, microlitic black rock, and of thinly scattered grains of quartz. The cement is brown and green clay, resulting from the decomposition of the lapilli.

ADDITIONAL REPORT BY MESSRS. BERTRAND AND ZÜRCHER.

[From S. Doc. No. 188, 56th Cong., 1st sess.]

NOTE ON THE CULEBRA AND EMPERADOR CUTS.

The works of the preparatory trench (cunette) and the wells accompanying them now enable us to understand with great certainty the composition and general nature of the soil to be removed. We can very happily say that the difficulties previously foreseen are greatly diminished by this more complete examination.

In the first explorations the explorers were naturally very much struck by the abundance of eruptive rocks, and it was supposed that the central frame of the Isthmus was formed of such rocks of great hardness, in which clay was found only in pockets more or less deep. The first works, on the contrary, by bringing to light a succession of clays of little solidity gave reason to fear the possibility of caving in and the necessity of very gentle slopes. Now, in reality, the axis of the Isthmus is formed of a series of sandstone, pudding stone, and marl of medium hardness, and the eruptive rocks spreading through these sheets or veins play only a secondary part. So far as hardness and solidity are concerned, it may therefore be said that the conditions will be more favorable than could at first be hoped.

The geological formation of the Isthmus seems from the studies already made to display, as the most ancient formation, an eruptive breccia, improperly designated Gamboa sandstone.[a]

It will be met with only in the Emperador cut, where it will constitute less than one-seventh of the excavation.[b] It would not reappear in the Culebra cut, even if the canal were made on a level. It seems to support in discordance the alternation of pudding stone, sandstone, and marl, already mentioned. This system, which is probably of the Upper Oligocene age, ends at the top by a bed of lignites and a bank of lenticular limestone (km. 49), the fossils in which give reason to attribute it to the Miocene. Subsequent eruptions, mostly of a basaltic nature, have given rise to veins, crossing the strata vertically, which, in places, have penetrated between the beds in long intrusive sheets, and which have cropped out in the hills (cerros). The importance of these eruptive rocks, so far as the excavations are concerned, is entirely secondary.

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[a] The Gamboa rock seems to be closely connected with the conglomerates of Bohio, in which M. Douvillé ascertained the presence of nummulites. It is likewise probable that the limestone containing nummulites in the neighborhood of Emperador, described by Mr. Hill, ought to belong to the same lower series, the age of which is probably Lower Oligocene or Eocene. All these determinations of age, however, are given only provisionally, as the study of the materials collected is not yet finished.

[b] The proportion of one-seventh has been calculated on the provisional cut estimated by the axis of the trench (cunette). As the eruptive rock is met with most in the deepest parts, where the width is less, it can be seen that this proportion ought to be considerably diminished, even allowing for the total excavation.

The position of the beds remains regular and evidently horizontal in the neighborhood of the veins and of the sheets, and there is no reason to fear any of the disturbances the possibility of which caused anxiety to the commission of studies of 1889, and which might have given rise to more or less important local slides.

It may be said practically that the whole of the work of the great cut (Culebra) must be made in the sedimentary system of the pudding stone, sandstone, and marl, the hardness of which, according to the old soundings, hardly exceeds No. VI of the scale adopted, and the rocks of which may all consequently be cut with steel. The examination of these lands shows that they will stand extremely well, and this fact has been practically proved by the experience of the preparatory trench (cunette), the slopes of which have been exposed to the air for more than two years. Even the marl, which, when in separate pieces, disintegrates and splits easily, resists very well in a mass, and may require, at the most, some local supports to protect it from the action of the atmosphere.

In the upper part the strata, which have been more or less affected, have assumed a red tint and a more clayey composition to a variable height, which in some places may be as much as 20 meters (65 ft.). These strata, which were almost entirely excavated by the old company with a width corresponding to that of the canal at its level, are those which caused the Cucaracha caving-in. Other little cavings-in occurred above Emperador (km. 51), and recently above Cucaracha. The question of these cavings-in was formerly a cause of great anxiety, but that cause no longer exists. That of Cucaracha was partly due to want of care in the method of constructing the embankments, and it was easily stopped by comparatively simple works of drainage. Besides at that point (from km. 54.5 to km. 55.5) the slope of the clays on the left bank is directed toward the cut, and may be as much as 20 degrees. Admitting, therefore, that special precautions must be taken to prevent the recurrence of such an accident, they would only extend over about 1 kilometer (0.62 mi.).

To sum up, the work will be done in sedimentary ground, the regularity of which enables precautions to be taken with great certainty. No very hard rocks will be encountered, excepting at the most a seventh of the Emperador cut. The other ground, which is of medium hardness, holds extremely well and will not need any supports; an average slope of 45 degrees (including the banquettes) can be safely used with them. There are no caving belts to fear, except the clays of the upper part which are already almost entirely excavated, and if any special precautions are to be taken against cavings-in, it would only be for the small extent of about 1 kilometer (0.62 mi.), where the slope of the clay is toward the cut.

NOVEMBER 19, 1898.

APPENDIX C.

DIMENSIONS OF LARGEST SHIPS AND IMPROVEMENTS IN CHANNELS AND HARBORS.

By M. ADOLPHE GUÉRARD.

[Translation.]

The law of Congress authorizing the construction of the Isthmian Canal says:

> Such canal shall be of sufficient capacity and depth as shall afford convenient passage for vessels of the largest tonnage and greatest draft now in use, and such as may be reasonably anticipated, and shall be supplied with all necessary locks and other appliances to meet the necessities of vessels passing through the same from ocean to ocean.

At the last meeting of the Board of Consulting Engineers it was resolved that information should be obtained concerning the dimensions of the largest vessels afloat, their number, and the nature and importance of the traffic in which they are engaged, and that this information would serve as a basis for the study of the question relating to the general dimensions to be given to the canal.

The following steamers are said to be the largest vessels in the world, viz, *Kaiser Wilhelm der Grosse*, of the North German Lloyd; *Oceanic*, of the White Star Line; *Deutschland*, of the Hamburg-American Line; *Celtic*, of the White Star Line; *Kronprinz Wilhelm*, of the North German Lloyd; *Cedric*, of the White Star Line; *Baltic*, of the White Star Line, and the *Caronia*, of the Cunard Line. The lengths of the above steamers vary between 197.80 meters (649 ft.) and 223 meters (732 ft.) over all.

In 1900 there existed few vessels drawing 8 meters (26.24 ft.) or over. It was mentioned, as an important instance, in 1886, that the *Gascogne* of the French Line had a maximum draft in the stern of 8.35 meters (27.39 ft.). The *Kaiser Wilhelm der Grosse*, built in 1897, and the *Oceanic*, in 1899, had drafts, with full cargo, of 8.84 meters (29 ft.) and 9.91 meters (32.51 ft.), respectively.

The Suez Canal was opened on January 1, 1890, to vessels drawing 7.80 meters (25.59 ft.) of water; prior to the above date only vessels drawing 7.60 meters (24.93 ft.) or less were admitted to the canal.

In the port of Marseille the north basin for half of its length was from 13 meters (42.65 ft.) to 18 meters (59.05 ft.) in depth, with entrance channels of the same depths. They had then not a number of piers measuring more than 18 kilometers (11.20 mi.), but only 1 kilometer (3,280 ft.) of piers, alongside of which was a depth of 8 meters (26.24 ft.), that is to say, a depth of 8 meters (26.24 ft.) below the lowest sea tide was assured. This was the pier of the north port, constructed about twenty years ago; all the other piers had less depth.

Genoa, whose entrance channels were as deep, did not have as many piers. Nevertheless, these two ports were considered to have the greatest improvements of any ports in Europe.

I remember having made, about twenty years ago, a report on all the ports of the world, classed according to the practical depths they offered to navigation. If my memory serves me right, there were not at that time more than forty ports in the world in which vessels drawing 8 meters (26.24 ft.) of water could enter and lay alongside piers for the purpose of loading and unloading their cargoes.

In 1900 the tendency for larger vessels became more pronounced. Work of deepening and enlarging the channel was then going on in the Suez Canal, as the company was anxious to facilitate the passage of vessels whose numbers and dimensions were growing to an extent unlooked for.

It was decided in the port of Marseille to give a depth of 8.50 meters (27.88 ft.) alongside the piers in course of construction in the new basin. The same tendency was apparent in other places.

The North German Lloyd, which had in 1897 placed in commission the *Kaiser Wilhelm der Grosse*, of a length over all of 197.80 meters (649 ft.) and 14,349 tons, was soon followed in 1899 by the *Oceanic* of the White Star Line, the length of which was 215 meters (705 ft.), with a tonnage of 17,274 tons; in 1900 by the *Deutschland*, of the Hamburg-American Line, measuring 209 meters (686 ft.) in length, 14,502 tons, and drawing 8.85 meters (29.03 ft.) of water. The same company launched, in 1901, the *Kaiser Wilhelm II*, which is 215.18 meters (706 ft.) in length, 20,000 tons, and drawing 8.85 meters (29.03 ft.), thereafter the *Kronprinz Wilhelm*, of 14,800 tons and a draft of 8.85 meters (29.03 ft.).

The same year was launched the *Celtic*, of the White Star Line, 213.50 meters (700 ft.) long, 20,900 tons, and a draft of 11.17 meters (36.64 ft.), and the following year the *Cedric*, having the same dimensions.

There then followed, in 1904, the *Baltic*, of the White Star Line, of the same dimensions as the *Celtic*, the *Caronia*, of the Cunard Line, with a length similar to the latter vessel, but with a draft of 9.75 meters (31.98 ft.).

This same company, the Cunard Line, is now constructing two big steamers, of 24 to 25 knots, whose size will be far greater than any vessel afloat. Of a gross tonnage of about 30,000 tons, they will measure 760 feet (231.63 m.) in length, beam 87 feet (26.51 m.); their draft will be 33 to 34 feet (10.05 to 10.36 m.) and, with Parson's turbines and 4 screws, capable of developing 70,000 horsepower. It is expected that these two steamers will travel at the rate of 24 to 25 knots; the highest speed attained up to the present time is 23.58 knots, made by the *Wilhelm II*.

The dimensions of the above-mentioned vessels are given in the following table:

Dimensions of largest ships, 1905.

Vessel.	Steamship line.	Date of construction.	Length at water line.		Length over all.		Width.		Depth.		Maximum draft.		Tonnage.
			Meters.	Feet.	Meters.	Feet.	Meters.	Feet.	Meters.	Feet.	Meters.	Feet.	Tons.
Kaiser Wilhelm der Grosse.	North German Lloyd ..	1897	191.20	627	197.80	649	20.12	66	13.12	43	8.85	29	14,349
Oceanic	White Star	1899	208.80	683	215.00	705	20.80	68	14.95	50	9.91	32.5	17,274
Deutschland	Hamburg-American ...	1900	202.00	663	209.00	686	20.43	67	13.00	42.5	8.85	29	14,502
Kaiser Wilhelm II	North German Lloyd ..	1901	206.70	676	215.48	707	21.95	72	16.01	52.5	8.85	29	20,000
Kronprinz Wilhelm	.....do	1901	195.00	640	202.00	663	20.12	66	13.12	43	8.85	29	14,800
Celtic	White Star	1901	207.35	680	213.50	700	22.88	75	14.95	50	11.17	36.5	20,904
Cedric	.....do	1902	207.35	680	213.50	700	22.88	75	14.95	50	11.17	36.5	21,035
Baltic	.....do	1904	216.00	709	223.49	733	22.87	75	14.95	50	.....	.....	24,600
Caronia	Cunard	1904	206.18	676	.....	.....	22.63	74	15.80	51.5	9.75	32	21,000
(In construction)	.....do	1905	224.00	735	231.63	759	26.51	87	18.28	60	10.20	33.5	30,000

The owners of tramp steamers are also following the example of regular lines of steamers. The British India is now constructing three steamers of 12,000 tons each, the Clan Line has ordered constructed six steamers of 7,000 tons each.

Moreover, the statistics of vessels passing through the Suez Canal show that the number of big steamers is increasing in a marked proportion. From 1893 to 1902 the number of vessels passing through varying from 3,000 to 4,000 tons and the percentage of vessels having a draft between 7.50 meters (24.60 ft.) and 7.80 meters (25.58 ft.) have been constantly increasing from 4.9 per cent up to 11.9 per cent. In 1902 it was 8.3 per cent, and the proportion of vessels drawing 7.80 meters (25.58 ft.) to 8 meters (26.24 ft.) was 3.3 per cent. In 1903 the percentage again went up to 10.3 per cent, and the proportion of vessels of 7.80 to 8 meters (25.58 to 26.24

ft.) was 4.8 per cent. For the first eight months of 1904 the proportions were 12.2 per cent and 5.5 per cent, respectively.

The enormous vessels above mentioned are only destined for service between North America and a few ports in Europe. They are very expensive to construct and their running expense is considerable.

Their great consumption of coal has attained to figures unheard of during the past years. It can be estimated by the following table showing the quantity of coal consumed by them in twenty-four hours under normal conditions:

FAST STEAMERS.

	Tons.
Kaiser Wilhelm der Grosse	580
Deutschland	650
Kaiser Wilhelm II	700
Kronprinz Wilhelm	630
Oceanic	550

STEAMERS OF MODERATE SPEED.

Celtic	220
Cedric	230
Baltic	240
Caronia	380

The two new turbine steamers of the Cunard Line which are expected to make 24.5 to 25 knots, will consume at least 1,000 to 1,100 tons per twenty-four hours, at normal speed.

The big steamers of the Messageries Maritimes of France, sailing between Bordeaux and La Plata, with a draft not exceeding 7 meters (22.96 ft.) and 150 to 155 meters (492 to 509 ft.) in length, consume a little less than half of the smallest figure above mentioned, with a speed of from 14.5 to 15 knots; their daily consumption of coal would be increased by more than 50 tons if they should force their speed 1 knot.

The steamers of the Chargeurs Réunis, of Havre, built especially for the same service, had, a few years ago, a net tonnage of 1,240 to 2,000 tons, a normal draft of 5.50 to 6.30 meters (18.04 to 20.66 ft.) and maximum draft of 6 to 7 meters (19.68 to 22.96 ft.). With a speed, varying according to the steamers, of from 7.75 to 12 knots, the consumption of coal for every twenty-four hours was 14 to 28 tons.

The increase in the consumption of coal is out of all proportion with the increase in speed. The steamship lines can not find a sufficient number of customers who will consent to pay for the value of this increase in speed, or obtain in the ports the large quantity of merchandise necessary to pay their expenses.

There are, therefore, difficulties and obstacles to the employment of large steamers even by the lines where business is most favorable. It is for this reason that the development of works in maritime ports follows instead of precedes the dimensions of the steamers, for these works are very expensive when they attain the proportions necessary for the operation of large vessels.

The pier walls of the Malapaga, at Genoa, constructed a few years ago at a foundation of −9 meters (29.52 ft.) only cost 2,100 francs per meter ($128 per ft.). The cost of the pier walls recently constructed in the port of Marseille, by means of compressed air, with a foundation as low as −10 and even −12 meters (32.80 and 39.37 ft.) did not exceed in both cases 2,800 to 3,400 francs ($171 to $207 per ft.). But we must bear in mind that material and labor in these two ports are very cheap, and at Genoa it is cheaper than in any other port of the world. At Havre, where the tide has a rise of 8 meters (26.24 ft.) and where the material and labor is very dear and there is also a bad foundation, a pier, now in construction, with an anchorage of −9 meters (29.52 ft.) will cost not less than 11,000 francs per running meter ($2,011 per yd.).

The following table taken from the report of Mr. Corthell, dated Buenos Ayres, November, 1900, contains interesting information concerning the principal ports of the world and the improvements made in order to meet the increase in the dimensions of steamers:

Increase of depth in harbors.

Port.	Year.	Existing depth.		Proposed depth.		Port.	Year.	Existing depth.		Proposed depth.	
		Low water.	High water.	Low water.	High water.			Low water.	High water.	Low water.	High water.
		Feet.	*Feet.*	*Feet.*	*Feet.*			*Feet.*	*Feet.*	*Feet.*	*Feet.*
Antwerp	1899	30	52	32.5	54.5	Liverpool	1899	30	50	.....	.....
Baltimore	1900	30	31.5	.....	.....	London	1898	24	44	30	50
Buenos Ayres	1899	21	23.7	23	25.7	Marseille	1898	55	55	.....	.....
Cardiff	1899	17	35	.....	.....	Newcastle	1899	21	26	25	30
Constantinople	1899	150	150	.....	.....	New Orleans	1900	24.8	26	35	36.2
Duhlin	1898	17	26	22	31	New York	1900	30	34.6	40	44.6
Genoa	1898	52	52	.....	.....	Rotterdam	1899	22	27.8	23	28.8
Hamburg	1899	18	24.6	22	28.6	Tampico	1899	26.2	27.4	28.8	30
Hongkong	1899	36	.....	.....	.....	Veracruz	1899	30	31.5	.....	.....
Lisbon	1898	28	39	.....	.....						

The depths given in the above table for Constantinople, Genoa, and Marseille, viz, 150 feet, 52 feet, and 55 feet, represent the depths found in certain parts of the port, outside of the pier walls, and which can be used by navigation; for instance, the depth of 150 feet at Constantinople is found in the Bosphorus, opposite Galata, and at the entrance of the Golden Horn. The anchorage alongside the piers built by the Société des Quais, Docks, and Entrepôts, of Constantinople, does not exceed 7 meters (22.96 ft.).

The depth of 52 feet at Genoa is found near the entrance of that port; the greatest depth alongside the piers is 9 meters (29.52 ft.) at Malapaga pier.

At Marseille there is a depth of 55 feet in the basin of the Maritime station, and in the National basins, for about half their length, at the breakwater, a depth reaching from 91 feet to 100 feet in the Pinede basin at the end and in continuation of the preceding basin. The depth alongside the piers does not exceed in any part 8 meters (26.24 ft.) in the basins south of the Pinede; it is 8.40, 9, and 12 meters (27.55, 29.52, and 39.37 ft.) in the basin of the Pinede, which has just been constructed.

According to Mr. Vernon Harcourt, August, 1905, the anchorages in English ports were approximately as follows:

Depths of anchorages in English ports.

Port.	Depth, low tide.		Depth, high tide.	
	Meters.	Feet.	Meters.	Feet.
Hull	.....	.....	9.00	29.5
Tyne, channel at Newcastle	6.10	20	.....	.....
Greenock, Great Harbor	8.55	28	.....	.....
Clyde, channel at Glasgow	6.86	22.5	.....	.....
Glasgow, Prince's dock	7.62	25	.....	.....
Tilbury dock	7.00	23	.....	.....
Barrow in Furness	.....	.....	9.14	30
Liverpool, lock at Alexander dock	3.20	10.5	8.84	29
Mersey bar	8.23	27	.....	.....
Cardiff, new lock	.....	.....	9.45	31
New Haven	3.66	12	.....	.....
Southampton	9.14	30	.....	.....
Dover	9.14-11.00	30-36	.....	.....

As showing the depths and improvements in progress in the harbors named, the following is taken from the report of the Ingénieurs des Services Intéresses, dated April, 1905:

Bremen—5.50 meters (18.04 ft.) at low tide.
Bremerhaven—4 meters (13.12 ft.) at mean low tide; 7 to 10.50 meters (22.96 to 34.44 ft.) at mean high tide.
Hamburg—7.50 to 8 meters (24.60 to 26.24 ft.) at low tide.
Amsterdam—7.80 to 8.50 meters (25.59 to 27.88 ft.).
Amsterdam Canal, North Sea—8.50 meters (27.88 ft.). Now being deepened to attain 9.80 meters (32.15 ft.) in 1907.
Ymuiden entrance—9 meters (29.52 ft.).
Hock, Holland—8.80 meters (28.87 ft.).
Anvers—9.10 meters (29.85 ft.).
Dunkirk, new Trystam lock—5 meters (16.40 ft.).
Boulogne—7.70 meters (25.26 ft.). Tide quay in course of construction.
Havre—6 meters (19.68 ft.); new lock, 3.50 meters (11.48 ft.); tide quay, 9 to 9.60 meters (29.52 to 31.16 ft.).
Barcelona—8 meters (26.24 ft.).
Marseille—8 meters (26.24 ft.); minimum depth of new basins, 8.50 meters (27.88 ft.), maximum, 30 meters (98.42 ft.); new quays, from 8.50 to 12 meters (27.88 to 39.37 ft.).

At Anvers the depth which was 6.63 meters (21.75 ft.) in the old basin, 7.18 meters (23.55 ft.) in the Kattendyke basin, built in 1860–61, 8.38 meters (27.49 ft.) in the Campine basin and in the Asea basin, 9.10 meters (29.85 ft.) in the Lefebvre basin (1887) and in the America (1887), will be also 9.10 meters (29.85 ft.) in the new basin now in course of construction.

For the new maritime station, which will soon be constructed, a depth of 10 to 11 meters (32.80 to 36.08 ft.) will be given. At the same time that they were increasing the depth they were giving larger and larger dimensions to the locks in the entrance basins. In the port of Marseille, for instance, the depth at exit at the drawbridge was, in 1860, 22 meters (72.17 ft.); in 1863, 28 meters (91.86 ft.); in 1880, 30 meters (98.42 ft.), and 50 meters (164.04 ft.) two or three years thereafter.

The lock at this station will have a depth of 10 to 11 meters (32.80 to 36.08 ft.) from the sill, 30 to 35 meters (98.42 to 114.82 ft.) in width, and 300 meters (984.25 ft.) of available length.

The large lock now being constructed in the port of Havre, and which will be completed in 1907, will have —3.50 meters (11.48 ft.) on the sills, a width of 30 meters (98.42 ft.) and available length of 250 meters (820.20 ft.). The tide at Havre fluctuates from 6.15 to 9.20 meters (20.17 to 30.18 ft.) and the duration of high tide is so long that the gates of the present lock remain open for nearly three hours.

The lock that will be constructed at the entrance of the new maritime station of Anvers will have a minimum depth of 10 to 11 meters (32.80 to 36.08 ft.) on the sills, 30 to 35 meters (98.42 to 114.82 ft.) wide, and 300 meters (984.25 ft.) in length.

Considerable efforts have been made in past years to increase the exits and entrances of harbors and their depths. In looking over the figures showing the length of the largest vessels afloat or in the course of construction it is noticed that if the anchorage hardly attains the draft of these vessels, the width, on the other hand, greatly exceeds that of the vessels. The reason for this difference is explained by the considerable and rapid increase in the expense of lowering the level of foundation, and therefore the piers with a depth of from 8 to 10 meters (26.24 to 32.80 ft.) are exceedingly rare, for in most cases they find it more advantageous to devote their resources to enlarging and improving the piers instead of increasing their depth. The increase in width and length facilitates the maneuvers of vessels; the increase in width is indispensable for the passage of war vessels, as they are considerably wider than vessels of commerce.

The Suez Canal was constructed with a depth of 8 meters (26.24 ft.) and bottom width of 22 meters (72.17 ft.).

In the Amsterdam Canal, at Ymuiden, a depth of 8.50 meters (27.88 ft.) and width of 25 meters (82.02 ft.), was made a few years later. The Corinth Canal has a depth of 9 meters (29.52 ft.) and a width of 22 meters (72.17 ft.). The Manchester Ship Canal, constructed twenty years after the Suez, has a depth of 9 meters (29.52 ft.) with a width of 36 meters (118.11 ft.).

Since the opening of the Suez Canal to navigation the company has never ceased to enlarge and deepen the sections. The section contained in the narrowest part of the canal has to-day a depth of 10 meters (32.80 ft.) and a bottom width of about 30 meters (98.42 ft.), and M. Quellennec will tell the Board of the efforts made by the company in order to obtain in the future, in a limited exit, a depth of 10.50 meters (34.44 ft.) and a bottom width of 50 meters (164.04 ft.).

Should it be necessary in order to determine the dimensions of the Panama Canal to take into account the exigencies of navigation we must not lose sight of the fact that navigation must shape its tools, the steamers, to conform with the sizes of the ports and canals.

Therefore it seems that with all the practical information available on this subject the minimum dimensions to be given to the canal can be easily determined, so that, in accordance with the law, it will not only afford free transit to the largest vessels now afloat but, better still, to those of the future.

Appendix D.

PRINCIPAL CANALS OF THE WORLD.[a]

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THE MANCHESTER SHIP CANAL.

By W. Henry Hunter.

1. *Depth of water.*—The depth in the canal, at low water, is 26 feet. Work is now in progress for an increase of the depth to 28 feet.

For the estuary section of the canal, 21 miles in length, the increase will be effected by the raising of the low-water level. For the remainder of the length, 14 miles (including the Manchester dock), the increase will be effected by lowering the bed of the canal by dredging.

2. *Width at bottom.*—For 28 miles, out of the total of 35 miles, the ruling width at bottom is 120 feet. That width has been and is being increased in many disconnected lengths to 180 feet; that is to say that lay-byes in which vessels can lie in order to discharge and load cargo have been formed on the sides of the canal. For 4 miles of the length the ruling width is 170 feet, which is being increased to 200 feet. The remainder of the length is occupied by dock coaling basins, etc.

3. *Inclination of side slopes.*—The inclinations of the slopes are:

In rock	5 vertical on 1 horizontal.
In clay	2 vertical on 3 horizontal.
In sand (glacial)	2 vertical on 3 horizontal.
In silt and light alluvial soil	1 vertical on 2 horizontal.
In peat and other vegetable deposit	1 vertical on 3 horizontal.

4. *Proportion between sectional areas of canal and vessels navigating canal.*—The minimum section of the canal (i. e., at Pool Hall cutting, where both sides are in rock) is 3,614 feet in area. The general section is 4,333 square feet in area.

The largest vessels which regularly navigate the canal at present are (1) twin-screw steamers of the *Somerset* class, 7,010 tons gross register, 460 feet between perpendiculars, by 58.2 feet beam, and (2) single-screw steamers of the *Silverlip* class, 470 feet between perpendiculars, by 55.2 feet beam. The draft of water of these vessels is 25 feet, and the areas of midship section are about 1,310 square feet and 1,240 square feet, respectively.

The proportions are therefore: Minimum section, $\frac{3614}{1310}=2.76$ to 1; general section, $\frac{4333}{1310}=3.30$ to 1.

[a] Memoranda prepared in accordance with the resolution of the Board of Consulting Engineers for the Panama Canal, passed at the meeting of the Board held September 8, 1905.

The rate of speed through the general section is 6 miles per hour, and through the minimum section (which covers a length of half a mile only), from 4 to 5 miles per hour. The slopes of the canal receive no injury at these speeds.

5. *Curvature.*—The worst curves on the canal are situated (1) at the mouth of the estuary of the Weaver, which flows into the canal about 10 miles above the entrance lock, and (2) near Runcora Bridge, 11¼ miles from the same point.

The following are the particulars of these curves:

	Radius.	Length.	Width of canal at center of curve.
	Feet.	*Feet.*	*Feet.*
Weaver Mouth	3,100	4,000	160
Runcora Bridge	3,300	1,200	135

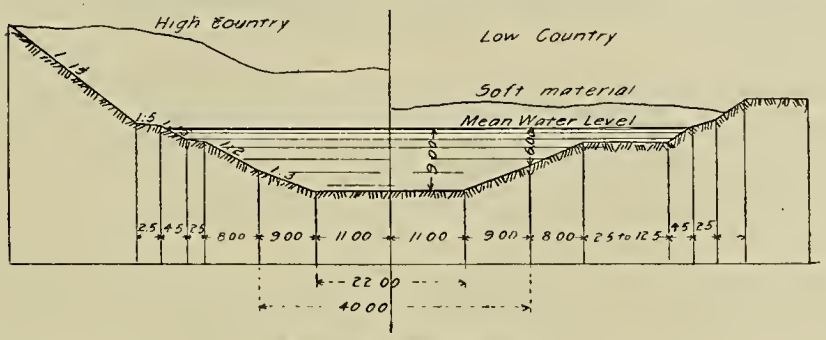
The curves are safely navigated daily by vessels of over 500 feet over all, but are undesirably sharp in radius. They did not form part of the original design of the canal, but were rendered necessary by provisions which were inserted in the act of Parliament which authorized the construction of the canal during the passage of the measure through the Houses of Parliament.

THE KAISER WILHELM CANAL (KIEL SEA CANAL).

By E. Tincauzer.

[Constructed and completed by the German Government.]

1. Length, 98 kilometers=61 miles.
2. Cross section:
   Bottom width, 22 meters=72 feet.
   Slope above bottom, 1:3.
   Slope above slope, 1:3, 1:2.
   Berm, 2.5 to 12.5 meters (8 to 41 ft.), 2 meters (6.5 ft.) under mean level.
   Slope above berm, 1:1.5.
   Berm above level, 2.5 meters (8 ft.) wide, with slope of 1:5. Then slope 1:1.5.



Cross section of Kaiser Wilhelm Canal.

3. The admitted range between the lowest level and the highest level is 1 meter (3.28 ft.).
4. Area at mean level, 413 square meters=4,444 square feet.
   Area 0.1 below mean level, 406 square meters=4,369 square feet.
   Area 0.2 below mean level, 400 square meters=4,304 square feet.
   Area 0.3 below mean level, 393 square meters=4,229 square feet.
   Area 0.4 below mean level, 386 square meters=4,153 square feet.
   Area 0.5 below mean level, 380 square meters=4,089 square feet.
5. Two terminal twin locks:
   Available length, 150 meters = 492 feet.
   Available width, 25 meters = 82 feet.
   Depth at mean level, 9.57 meters (31.39 ft.) on the sill.
6. Curvature:
   3 curves with a radius of 6,000 meters = 6,562 yards.
   4 curves with a radius of 5,000 meters = 5,468 yards.
   10 curves with a radius of 3,000 meters = 3,281 yards.
   2 curves with a radius of 2,500 meters = 2,734 yards.
   1 curve with a radius of 2,000 meters = 2,187 yards.
   1 curve with a radius of 1,700 meters = 1,859 yards.
   1 curve with a radius of 1,500 meters = 1,640 yards.
   4 curves with a radius of 1,000 meters = 1,094 yards.
   26 curves.

In the curves with a radius of 1,000 to 2,500 meters (1,094 to 2,734 yds.) an increase of breadth of bottom is made by the formula: $26 - \frac{R}{100}$; therefore—

Curve of 1,000 meters has increase of breadth of bottom of $26 - \frac{1000}{100} = 16$ meters = 52.5 feet.
Curve of 1,500 meters has increase of breadth of bottom of $26 - \frac{1500}{100} = 11$ meters = 36.0 feet.
Curve of 1,700 meters has increase of breadth of bottom of $26 - \frac{1700}{100} = 9$ meters = 29.5 feet.
Curve of 2,000 meters has increase of breadth of bottom of $26 - \frac{2000}{100} = 6$ meters = 19.6 feet.
Curve of 2,500 meters has increase of breadth of bottom of $26 - \frac{2500}{100} = 1$ meter = 3.2 feet.

7. Lake navigation, about 5 kilometers = 3 miles.
8. Passing places: The canal had seven places where ships could pass, which were 12 to 14 kilometers (7.4 to 8.7 mi.) distance from each other. At present, I believe, the number of these places is greater.

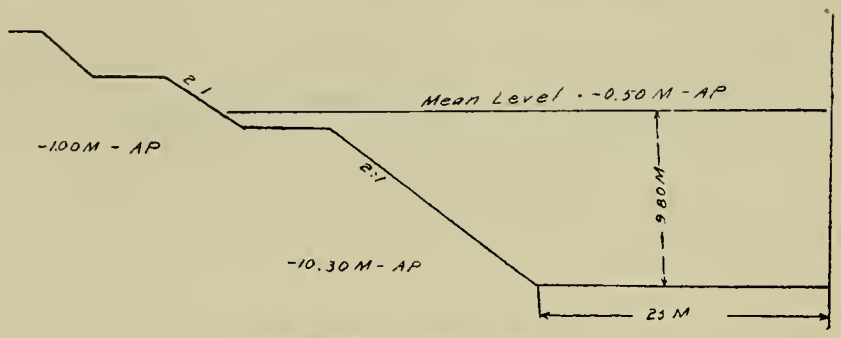
THE NORTH SEA CANAL.

By J. W. Welcker.

Constructed first by the private North Sea Canal Company, afterwards bought and successively enlarged by the Netherlands Government.

Length, 25 kilometers (15.5 mi.).

The enlargement in execution aims to afford the following dimensions:



Cross section of North Sea Canal (half).

Width at mean level differs at different locations; minimum, 68 meters (223 ft.).

Generally the canal level is above mean level 0.50 meter (19.6 in.), A. P.,[a] and is not constant, the canal being used for drainage of adjacent country.

Terminal lock at Ymuiden, dimensions: Depth at mean level, 9.50 meters (31.1 ft.) on sill; clear length, 225 meters (738 ft.); clear width, 25 meters (82 ft.); surface of wet canal section, minimum 670 square meters (7,209 sq. ft.).

Old terminal lock at Ymuiden (formerly the only one) is now used only by vessels of average and smaller dimensions.

The curves of the canal line are all of great radii and do not enter into consideration in respect to the passage of largest vessels, owing to the great width of cross section in relation to depth.

The canal will be completed on the enlarged dimensions in 1906, at the latest in 1907.

[a] A. P. is the mark of zero at Amsterdam range, being the datum plane of all levels in the Netherlands.

THE SUEZ CANAL.

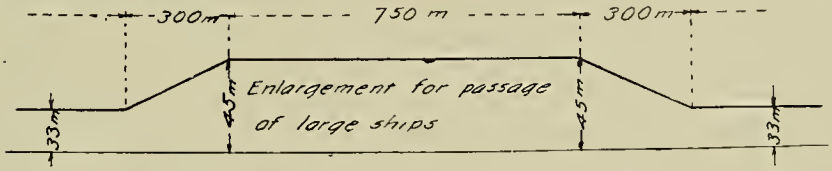
By E. Quellennec.

1. *Depth of water.*—The depth in the canal at low water is at least 9.5 meters (31.1 ft.). Work is now being done to increase the depth at low water to 10.5 meters (34.4 ft.); the depth of 10 meters (32.8 ft.) has already been attained in many parts of the canal.

The ordinary range between high and low water varies according to the regions. In the north region the range, which is 0.40 meter (16 in.) at Port Said, gradually decreases up to Lake Timsah. In the central region, comprising Lake Timsah, the Serapeum cut, and the Large and Small Bitter Lakes, the level is nearly constant; in the southern region the range increases gradually from the Bitter Lakes to Suez, where it attains 2.46 meters (8.07 ft.).[a]

2. *Bottom width.*—The bottom width (or, to state it more clearly, the width at the depth of 9.5 meters (31.1 ft.), as the bottom is generally lower) varies from 33 to 36 meters (108.26 to 118.11 ft.); the minimum width is found where there are long inclined slopes, the maximum width where steeper slopes. In the passage through the Small Bitter Lake the bottom width is 36 meters (118.11 ft.); as to the Large Bitter Lake it is in reality a large inland lake, with a depth of 10 meters (32.80 ft.) at least on a width of 6 kilometers (3.73 mi.). The central part of Timsah Lake also forms a basin of 9.5 meters (31.1 ft.) in depth for a distance of 2 kilometers (1.24 mi.) and a width of 500 meters (1,640 ft.). The bottom is wider in the curves. (See paragraph below relating to curves.)

There are in the canal 23 sidings with a bottom width of 45 meters (147.63 ft.) to allow the largest ships to pass each other; they are 750 meters (2,460 ft.) in length, with a narrowing of 300 meters (984 ft.) in length at each end.[b]



In reference to the bottom width, the 167.5 kilometers (104.08 mi.) of the canal are divided as follows:

Section.	Bottom width.		Length.	
	Meters.	Feet.	Kilometers.	Miles.
Channel of Port Said roadstead	300	984	3	1.86
Entrance channel of outer harbor	150	492	2	1.24
Port Said Harbor	Varying.		4	2.48
Lake Timsah	500	1,640	2	1.24
Large Bitter Lake	6,000	19,680	15	9.32
Channel of Suez roadstead	100	328	2.5	1.55
Canal (including Small Bitter Lake)	33 to 36	108 to 118	139	86.37
Total length			167.5	104.08

[a] When the influence of the sea wind is combined with the tide, the level of the sea may rise 1 foot more at Suez and 2 feet more at Port Said, consequently the difference between low water and exceptionally high water may be 1 meter (3.28 ft.) at Port Said and 2.75 meters (9.02 ft.) at Suez.

[b] Ordinary sized ships can pass each other in every part of the canal except in certain curves and certain parts of Small Bitter Lake where there are no mooring piles; also in some parts of the Suez section where there are rocky slopes. When the width of two ships exceeds 31.40 meters (103 ft.) ships can not pass each other except in the sidings in Lake Timsah and in Large Bitter Lake. Ships can freely navigate as in the open sea for a distance of 15 kilometers (9.32 mi.) in Large Bitter Lake; they can anchor in Lake Timsah. When two ships pass each other in the canal, one must be made fast to the mooring piles.

The bottom width is 45 meters (148 ft.) for the 17 kilometers (10.5 mi.) in length of sidings. At the same time that the canal is being deepened it is also being widened, with the object of uniting the sidings and giving, therefore, a bottom width everywhere of 45 meters (148 ft.), with a depth of 10.5 meters (34.4 ft.).

3. *Inclination of slopes.*—In sand, hard clay, and rock,[a] 1 vertical to 2 horizontal (except in certain rocky parts where the inclination is 1 on 1); in clay, from 1 vertical to 3 or 3.5 horizontal; in muddy sand and in mud, from 1 vertical to 4 or 5 horizontal.

Berms had been made in the region of low banks during the construction of the canal. Where the primitive slopes still exist, the berms, which had originally 5 to 14 meters (16.4 to 45.9 ft.), are still there, worn away more or less by erosion; everywhere else there are no berms. In the cuts the berms were left out during the construction for reasons of economy.

4. *Cross sections.*—The average cross sections are figured, four in number, in the annexed sketch. In these sketches the original sections are shown just as they were executed at the time of the construction of the canal. Since then the depth has been changed from 8 to 9.50 meters (26.24 to 31.1 ft.) at least and the bottom width from 22 to 33 meters (72.17 to 108.26 ft.) at least.

Leaving out the lakes, sidings, and curves, where the bottom width is greater, the wet section of the canal at low water varies at the present time from 540 square meters (5,813 sq. ft.) to 680 square meters (7,320 sq. ft.); at highest water, the wet section varies from 560 square meters (6,028 sq. ft.) to 780 square meters (8,396 sq. ft.).

5. *Authorized draft.*—At present the authorized draft is 8 meters (26.24 ft.); it will be 8.23 meters (27 ft.) from January 1, 1906.

6. *Speed of ships.*—The speed regulation is 10 kilometers per hour (6.2 mi. or 5.4 knots).[b] The largest ships steer freely at this speed.

The passage of ships at a speed of 10 kilometers produces a lowering of the water level, a contrary current to the course of the ship, and a wave which follows the ship. For the very large ships these effects are well pronounced at a speed of 10 kilometers and they cause in the soft soil an erosion of the slopes and berms. When the speed exceeds 10 kilometers, these effects are increased and the erosion of the slopes and berms becomes very marked.

7. *Currents.*—The Bitter Lakes form in the intermediate region of the canal a reservoir with a level nearly constant. As the water level varies at Port Said, and especially at Suez, a current is formed which flows sometimes from north to south, and at other times from south to north.[c] In the Port Said section the velocity of the current reaches to 0.60 meter (1.96 ft.) per second (2,160 m. per hour, or 1.1 knots), it is frequently 0.30 meter (0.98 ft.) per second (1,080 m. per hour, or ½ knot).

In the Suez section the velocity of the current very often exceeds 0.60 meter (1.96 ft.) per second (2,160 m. per hour, or 1.1 knots), and reaches at times 1.35 meters (4.42 ft.) per second (4,860 m. per hour, or 2.6 knots).

In the latter case the ships do not steer very well with the current running in; however, the navigation is never interrupted on account of the current. In the Port Said section ships can moor with a current running in either direction; in the Suez section they always moor with the current running out.

8. *Proportion between sectional areas of canal and areas of midship sections of vessels.*—The largest steamers that passed through the canal in 1904 are the *Grosser Kurfürst*, of the North German Lloyd, and the British cruiser *Terrible*.

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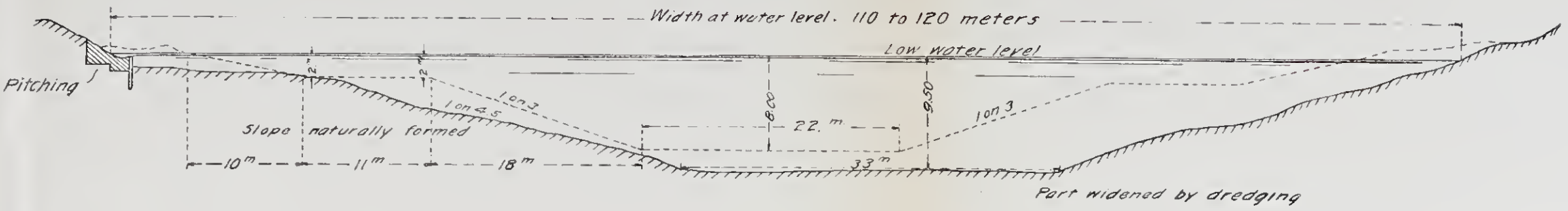
[a] Rock is found generally only at the bottom of the canal. There are some rocky strata intermingled in the hard clay to be met from a depth of 5 meters (16.4 ft.).

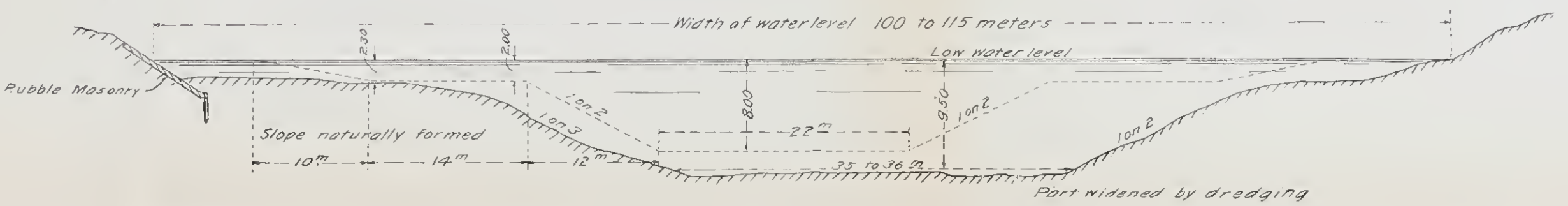
[b] However, a speed of 12 kilometers (7.45 mi. or 6.47 knots) is attained in a straight run of 46 kilometers (28.57 mi.), beginning at Port Said, where the wet section exceeds 650 square meters (777 sq. yds.), and a speed of 14 kilometers (8.70 mi. or 7.55 knots) in Small Bitter Lake. But for the large ships, owing to the resistance encountered, and which increases rapidly with the speed, the speed is reduced to 10 kilometers (6.2 mi. or 5.4 knots).

[c] Between the Bitter Lakes and Suez, the current changes generally four times a day, according to the tide in the Red Sea. Between Lake Timsah and Port Said changes of the currents are irregular, owing to the influence of the wind on the sea level at Port Said.

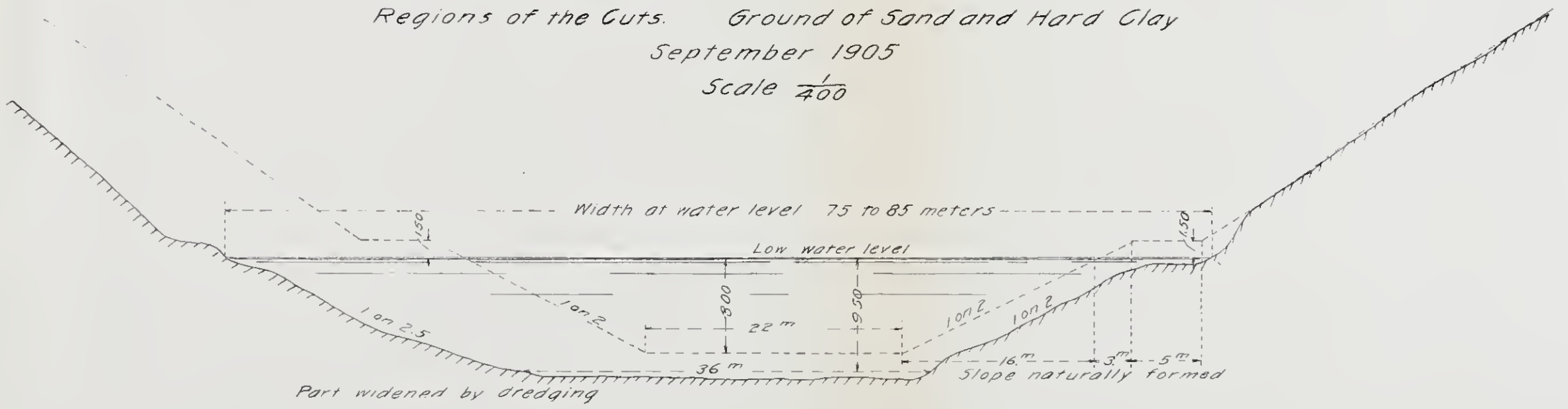
Suez Canal
Average Cross Section N°1
Region of Low Banks Ground Muddy
September 1905
Scale 1/400



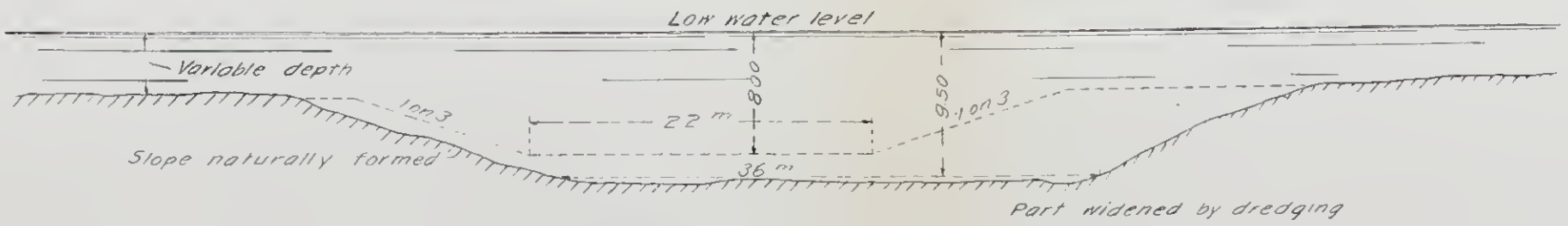
Suez Canal
Average Cross Section N° 2
Regions of Low Banks. Ground of Sand and Hard Clay
September 1905
Scale 1/400



Suez Canal
Average Cross Section N° 3
Regions of the Cuts. Ground of Sand and Hard Clay
September 1905
Scale 1/400



Suez Canal
Average Cross Section N°4
Lake Regions
September 1905
Scale 1/400



The dimensions of these vessels are:

	Length.		Beam.		Draft.		Midship section.	
	Meters.	Feet.	Meters.	Feet.	Meters.	Feet.	Square meters.	Square feet.
Grosser Kurfürst	170.86	560.56	19.00	62.33	7.98	26.18	142	1,529
Terrible	152.40	500.00	21.64	71.00	8.00	26.24	155	1,668

The above vessels passed through the canal without difficulty at the speed regulation of 10 kilometers (6.2 mi. or 5.4 knots) per hour. The *Grosser Kurfürst*, which passes through the canal regularly, has made many passages in both directions during the past four years.

The proportion between the minimum section of the canal and midship section of these vessels is, for the *Grosser Kurfürst*, $\frac{540}{142}=3.8$; for the *Terrible*, $\frac{540}{155}=3.5$.

In 1902 the Japanese battle-ship *Mikasa* passed through the canal when the wet section in certain parts was only 515 square meters (5,544 sq. ft.).

The dimensions of this vessel are:

	Length.		Beam.		Draft.		Midship section.	
	Meters.	Feet.	Meters.	Feet.	Meters.	Feet.	Square meters.	Square feet.
Mikasa	122.00	400.26	23.20	76.11	8.00	26.24	165	1,808

The proportion between the minimum wet section of the canal and the midship section is therefore for the *Mikasa*, $\frac{515}{165}=3.12$.

In 1898, the steamer *Barbarossa*, of the North German Lloyd, and the British battle ship *Victorious* passed through when the minimum wet section was 490 square meters (5,275 sq. ft.).

The dimensions of those vessels are:

	Length.		Beam.		Draft.		Midship section.	
	Meters.	Feet.	Meters.	Feet.	Meters.	Feet.	Square meters.	Square feet.
Barbarossa	160.40	526.24	18.29	60.00	7.80	25.59	135	1,453
Victorious	118.90	390.09	22.86	75.00	7.80	25.59	155	1,668

The proportions are, for the *Barbarossa*, $\frac{490}{135}=3.63$; for the *Victorious*, $\frac{490}{155}=3.16$.

This shows, therefore, that the proportion between the wet section of the canal and midship section can be reduced to 3, thereabout, for the men-of-war, and in the neighborhood of 3.5 for the liners. But this applies to vessels which steer freely and are well equipped and manned. For the freight carriers, which do not possess these advantages, the proportion must equal 4 to 1 to allow them to pass conveniently at the speed of 10 kilometers (6.2 mi. or 5.4 knots).

9. *Curves.*—There are fifteen curves in the Suez Canal, the elements of which are indicated in the following table:

Elements of curves.

Designation of curve.	Radius.		Center angle.	Length in circumference.		Bottom width at summit of curve.		Observations.
	Meters.	Yards.		Meters.	Yards.	Meters.	Feet.	
			° ′					
Port Said	2,950	3,226	34 31	1,823	1,994	450	1,476	This curve is included in the port of Port Said.
Kilometer 50	7,400	8,093	8 33	1,102	1,205	56	184	
Kilometer 52	2,000	2,187	16 40	573	627	56	184	
Kilometer 58	2,000	2,187	21 56	714	781	56	184	
El Ferdane	2,350	2,570	43 8	1,777	1,943	56	184	
North El Guisr	2,200	2,406	32 56	1,278	1,398	80	262	These two curves join to form a reverse curve.
South El Guisr	2,600	2,843	24 50	1,104	1,207	46	151	
Chantier VI	2,150	2,351	35 25	1,326	1,450	46	151	
Lake Timsah	1,300	1,422	90 41	2,010	2,198	500	1,640	This curve forms the side south of the central basin of Lake Timsah.
Toussoum	2,500	2,734	26 52	1,178	1,288	46	151	
North Small Bitter Lake	3,000	3,280	42 28	2,224	2,432	40	131	
South Small Bitter Lake	2,600	2,843	27 57	1,279	1,399	44	144	
Kilometer 146	8,900	9,733	7 49	1,231	1,346	50	164	
Kilometer 152	4,900	5,359	12 32	1,026	1,122	56	184	
Suez	3,200	3,500	41 33	2,329	2,547	40	131	

Leaving out of consideration the curve of Lake Timsah, which only forms one side of a large basin 2 kilometers (1.24 mi.) in length by 500 meters (1,640 ft.) in width, it will be noticed that there are five curves with a radius comprised between 2,000 and 2,350 meters (2,187 and 2,570 yds.), but work is now in progress to rectify these five curves and increase their radius to 2,500 meters (2,734 yds.) at least.

The following table shows the original and actual curve radii and the radii to be obtained after the completion of the work now in progress:

Designation of curve.	Original radius.		Actual radius.		Radius after rectification.	
	Meters.	Yards.	Meters.	Yards.	Meters.	Yards.
Port Said	2,950	3,226	2,950	3,226	2,950	3,226
Kilometer 50	2,000	2,187	7,400	8,093	7,400	8,093
Kilometer 52	2,000	2,187	2,000	2,187	3,000	3,280
Kilometer 58	2,000	2,187	2,000	2,187	2,600	2,843
El Ferdane	2,100	2,296	2,350	2,570	2,500	2,734
North El Guisr	1,000	1,093	2,200	2,406	2,500	2,734
South El Guisr	2,150	2,351	2,600	2,843	2,600	2,843
Chantier VI	1,750	1,914	2,150	2,351	2,500	2,734
Lake Timsah	300	328	1,300	1,422	1,500	1,640
Toussoum	2,000	2,187	2,500	2,734	2,500	2,734
North Small Bitter Lake	3,000	3,280	3,000	3,280	3,000	3,280
South Small Bitter Lake	2,000	2,187	2,600	2,843	3,000	3,280
Kilometer 146	3,000	3,280	8,900	9,733	8,900	9,733
Kilometer 152	3,000	3,280	4,900	5,359	4,900	5,359
Suez	3,200	3,500	3,200	3,500	3,200	3,500

Moreover, the bottom width of the curves will be increased by 8 to 15 meters (26 to 49 ft.). The improvements of the curves will be shortly accomplished.

The first table shows that the previously adopted widening over 33 meters (108 ft.) was at least 13 meters (43 ft.) when radius is inferior to 3,000 meters (3,280 yds.), and 7 meters (23 ft.) when radius is equal or superior. Whenever the topographic conditions permitted the bottom widths of the curves have been further enlarged.

The theoretical rule consists in widening the bottom of the curves so that the longest ship sailing on the circumference of a curve almost always preserves in its own direction a free space equal to 1½ times its length from the slope of the concave side. The present drawings of the curves of the Suez Canal are based on a maximum length of ships of 170 meters (558 ft.); the drawing concerning the work now in progress is based on a maximum length of ships of 200 meters (656 ft.).

The convex side of the curves is generally polygonal, in order to facilitate the mooring of ships along the sides of this polygon, so that two ships can pass each other in the curves.

It is possible for vessels to pass in curves of small radius if the curves are conveniently widened. In 1884 the steamer *Austral*, of the Orient Line (length, 460 ft., breadth, 44.5 ft., and draft, 24.5 ft.), passed through the curves of North El Guisr and Lake Timsah, of which the radii were 1,400 meters (1,531 yds.) and 600 meters (656 yds.), respectively. The bottom width of the first curve was 42 meters (138 ft.) and of the second 280 meters (919 ft.), but the passage was effected under great difficulty.

In fact, experience shows that the radii of curves should not be inferior to 2,500, even 3,000 meters (2,734 to 3,280 yds.) if vessels are to pass conveniently and regularly at the speed of 10 kilometers (5.4 knots) in a narrow canal.

THE ST. MARYS FALLS CANAL.

By Joseph Ripley.

The waterway connecting Lake Superior with Lake Huron, known as St. Marys River, has a varying width of one-half mile to 20 miles between the mainlands, and is divided by islands into numerous channels, the shortest route between the two lakes being 61 miles. The outflow is 60,000 cubic feet per second at low water and 115,000 at high water. The fall is about 22 feet, 20 feet of which is concentrated at the falls or rapids at Sault Ste. Marie.

The ship canal built by the State of Michigan in 1853 to 1855, along the south side of the rapids, was 1½ miles long, 13 feet deep, 64 feet wide at the bottom, and 100 feet wide at the water surface, the slopes being paved with stone. There were two tandem locks of masonry, each 350 by 70 feet, having a lift of 10 feet each and a depth of 11½ feet on the miter sills.

The only navigable channel below the canal was through Lake George, and that was limited to 8 feet draft. The crossings at shoals were deepened to 12 feet for widths of 100 to 200 feet during the years 1857 to 1869. The Weitzel lock, 515 feet long, 80 feet wide in the chamber and narrowing to 60 feet at the gates, with 17 feet depth of water on the miter sills, and 20 feet lift, was built south of the State lock in the years 1870 to 1881, and the depth of the canal was increased to 16 feet, the mean width to 160 feet, and the stone slope walls replaced with vertical faced timber piers; also, the depth of river channels by the Lake George route was increased to 16 feet and the widths made 250 or 300 feet.

The State locks were replaced by the Poe lock in 1887 to 1896, its dimensions being 800 feet long, 100 feet wide, with 22 feet of water on the miter sills, and lift of 20 feet. The canal was deepened to 25 feet, and the entrance piers extended so that the canal is now 1⅝ miles long, with a variable width of 500 feet at the upper entrance, 108 feet at the head gate, 270 feet at the basin above the locks, and 1,000 feet at the lower entrance. The Hay Lake route, with a saving of 11 miles in distance, was dredged during the years 1882 to 1894 to a depth of 20 feet for a least width of 300 feet.

The improvements made previous to 1900 were referenced to the mean stage of water, but all improvements are now planned with reference to the lowest stage of water, the lowering of the grade planes being one-half of a foot above the locks, 4 feet just below the locks, and 2¾ feet near the mouth of the river. The approved betterment of the lockage facilities includes the widening of the canal for passageway between the pivot pier and north abutment of the railway swing bridge, and the construction of a lock 1,300 to 1,400 feet long, 75 to 80 feet wide, and about 25 feet depth on the miter sills.

A safe and convenient channel between the two lakes is now being excavated for a draft of 21 feet and least width of 300 feet where used by ships moving in one direction only, and a width of 600 to 1,500 feet where traversed by ships moving in both directions. The improved areas extend for a total distance of 34 miles, the maximum for any one of the routes being 21 miles. In accordance with a recent act of Congress, estimates have been prepared for deepening the present channel to 25 feet.

The Canadian government built a canal along the north side of the rapids in 1887 to 1895, its length being 1⅞ miles, width 150 feet, and depth 22 feet, with a lock 900 feet long, 60 feet wide, and 22 feet depth on the miter sills. Both the entrances are now being improved by widening to 500 feet and extending the piers about 800 feet.

Curvature.—The center lines of both the American and Canadian canals are straight and extend nearly east and west. The sailing courses through the river are on tangents, which in all cases are extended to point of intersection, the angle being deepened across the inner side for widths of 600 feet up to 1,100 feet, depending on size of angle, character of material, exposure to storms, and depth of adjacent waters. There are six sailing courses between Lake Superior and the canal, fifteen courses between the canal and Lake Huron via the Middle Neebish, and thirteen via the West Neebish route.

Above canal.

Angle.	Width of channel.	Deflection.	Radius of curvature.
	Feet.	°	*Feet.*
No. 1	800	22	9,000
No. 2	800	43	6,000
No. 3	1,000	36	4,000
No. 4	1,000	18	7,000
No. 5	1,500	19	7,000
No. 6	1,000	15	8,000

Below canal, Middle Neebish route.

Angle.	Width of channel.	Deflection.	Radius of curvature.
	Feet.	°	*Feet.*
No. 1	1,000	44	2,600
No. 2	600	12	6,000
No. 3	1,000	18½	4,700
No. 4	3,000	9¼	7,000
No. 5	300	38½	3,000
No. 6	300	64¾	2,100
No. 7	600	43¼	2,800
No. 8	300	61½	2,400
No. 9	3,000	63	3,000

Remainder of angles in deep water over half a mile wide.

Below canal, West Neebish route.

Angle.	Width of channel.	Deflection.	Radius of curvature.
	Feet.	°	*Feet.*
No. 1	1,000	44	2,600
No. 2	600	12	6,000
No. 3	1,000	18½	4,700
No. 4	300	26¾	12,000
No. 5	300	41½	8,500
No. 6	300	25	13,000
No. 7	300	40¼	5,000

Same as Middle Neebish.

Side slopes.—

Lock walls, American and Canadian canals ..... Vertical
Revetment piers:
American canal ..... 12 on 1
Canadian canal ..... 4 on 1
River channels:
In sand ..... 1 on 2
In clay ..... 1 on 1
In rock, excavated in the dry ..... Vertical
In rock, excavated in the wet, variable ..... 3 on 1 to 1 on 1

A floating timber fender, 5 feet wide, is kept along both sides of the Canadian canal.

The speed of vessels through the improved channels is now limited to 9 miles per hour. On completion of the improvements now in progress the passage of the St. Marys River can be made with safety by day or night through an easily navigated channel at speeds of 9 to 12 miles per hour, without danger to ships or damage to the banks of the channel.

THE CORINTH CANAL.

By E. Quellennec.

The total length of the Corinth Canal, in a straight line, is 6,300 meters (about 4 miles). The great central cut is 4,000 meters long (2½ miles). The summit of the cut is 79.20 meters (260 ft.) above sea level, and the depth of water is 8 meters (26.24 ft.). The total excavation is 87 meters (286 ft.), and is at present the greatest cut in the world. In the lower part of the cut is found a large mass of calcareous clay, and although this clay is not very hard, it is sufficiently compact to need blasting. The loose pieces are transformed by atmospheric influence into dust and mud, but in a body it keeps in good condition below and above water; the surface only is slightly worn.

The clay in the center of the cut extends from the bottom of the cut to 50 meters (164 ft.) above the bottom. Above the clay is found a mixture of gravel and sand, more or less cemented by a calcareous cement. Part of this concrete is very hard and some is soft. Above this mixture there is calcareous tufa and in the upper part gravel, sand, and earth. All of these layers are almost horizontal, but cut up and displaced by numerous outthrows.

In the upper part of the cut the slopes have an inclination of 1 on 1, but in tufa, conglomerates, and clay the slopes are maintained as steep as possible and their inclination varies from 2.5 on 1 to 3 on 2 (2.5 vertical and 1 horizontal to 3 vertical and 2 horizontal).

In the wet section the sides are protected by retaining masonry walls at an inclination of 4 on 1 (4 vertical and 1 horizontal). These walls rise 2 meters (6.56 ft.) above the water level and form on each side benches of an average width of 2.50 meters (8.20 ft.). The bottom not being sheeted, the clay is in direct contact with the sea water. The weaker parts of the conglomerates and tufa, especially those dislocated (disloqués) by outthrows, are covered by a masonry sheeting. Advantage is taken of the hard layers to form benches upon which rest these sheetings.

The total amount of material excavated for the construction of the canal was 11,500,000 cubic meters (15,000,000 cu. yds.). From the central cut alone the material excavated amounted to 10,500,000 cubic meters (13,500,000 cu. yds.). During the construction the maximum amount of material excavated for a year was 1,800,000 cubic meters (2,350,000 cu. yds.). During the six years of greatest activity the average annual excavation in the central cut was 1,400,000 cubic meters (1,830,000 cu. yds.).

The bottom width of the canal is 21 meters (68.89 ft.) and the width at water level is 24.60 meters (80.70 ft.).

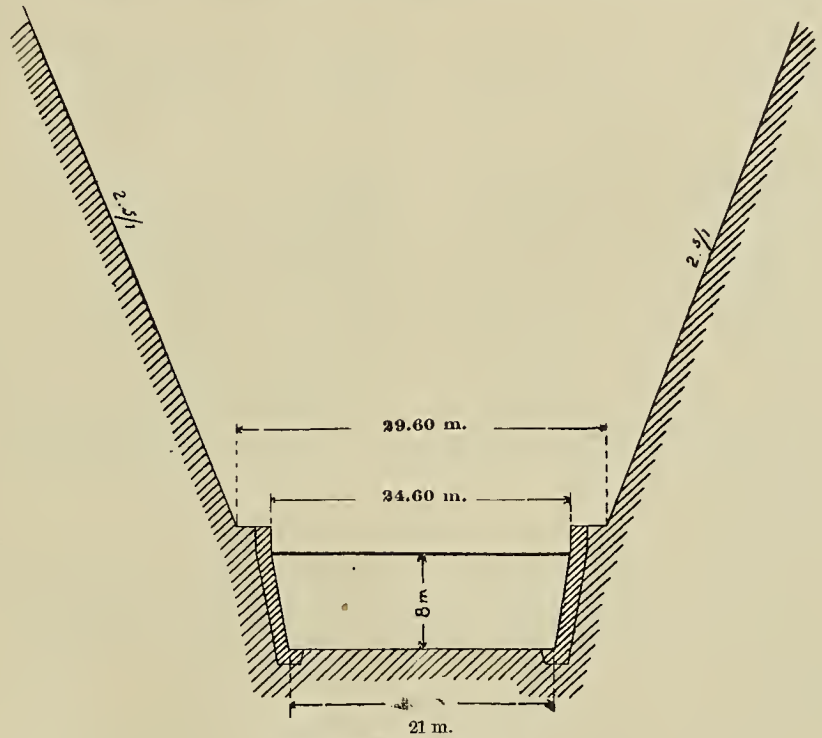
The depth at low water is 8 meters (26.24 ft.), and the area of the wet cross section is 182.40 square meters (1,959 sq. ft.). With these restricted dimensions the Corinth Canal is able to accommodate only ships of small or moderate tonnage. Nevertheless, we might draw some information from the transit of vessels in the almost rectangular wet section of the canal, similar in shape to the projected wet section of the Culebra cut.

I have not at hand detailed information on this subject. I can say, however, that among the steamers that passed through the canal was the steamer *Lusitania*. The dimensions of this ship are:

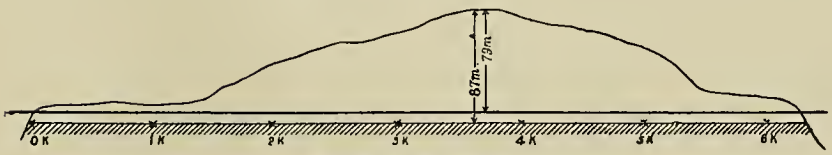
	Length.		Beam.		Draft.		Midship section.	
	Meters.	Feet.	Meters.	Feet.	Meters.	Feet.	Square meters.	Square feet.
Lusitania	97.53	319.97	12.95	42.48	6.00	19.68	68	732

The proportion between the wet section of the canal and the midship section is, for the *Lusitania*, $\frac{1\,8\,2.4}{6\,8} = 2.69$.

When such a steamer is steered well, it can pass through the canal without much difficulty, but if it is not under good control, it inevitably strikes the side walls repeatedly during the transit.



Cross section of Corinth canal.



Profile of Corinth Canal.

DIMENSIONS OF THE CANALS OF EUROPE.

By A. Guérard.

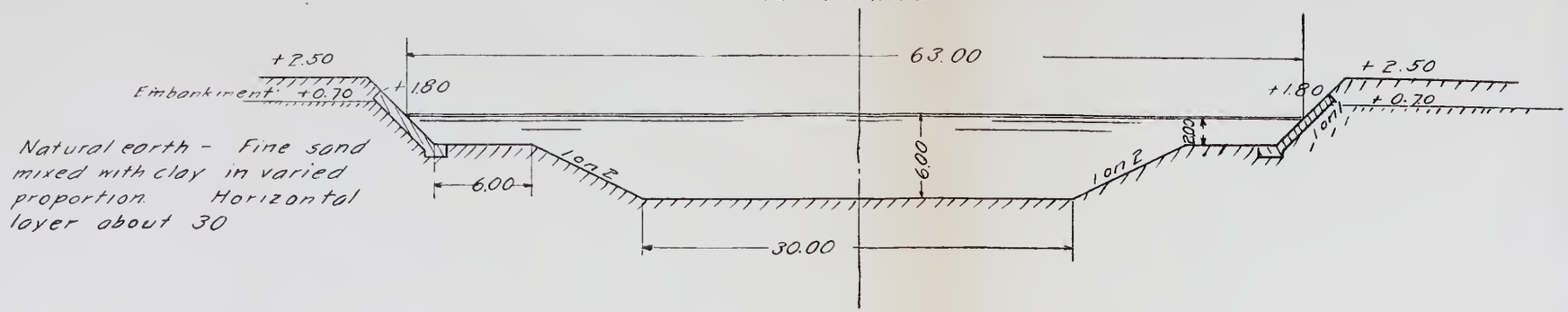
Name of canal.	Dimensions.						Locks.							Observations.
	Length.		Depth.		Bottom width.		Number.	Available length.		Depth on sills.		Width.		
	Km.	Miles.	Meters.	Feet.	Meters.	Feet.		Meters.	Feet.	Meters.	Feet.	Meters.	Feet.	
1. St. Louis Canal	3	1.86	6.00	19.68	30	98.42	1	160.00	524.93	7.50	24.60	22.00	72.17	Built by the Government.
2. Canal de Bouc, at Mantignes, from the sea to Pond of Berre.	5	3.10	6.00	19.68	12	39.37								Approximate length; built by the Government.
3. Suez Canal:														
Actual condition	167.5	104.08	9.50	31.16	33	108.26								Built by a company.
In execution	167.5	104.08	10.50	34.44	45	147.63								
4. Amsterdam Canal, North Sea:														
Actual condition	25	15.53	8.50	27.88	35	114.82	1 single	225.77	740.70	9.60	31.49	25.00	82.02	Built by the Government, which is continuing its improvement.
In execution	25	15.53	10.30	33.79	50	164.04	1 double	120.00	393.70	7.25	23.78	18.05	59.21	
								70.00	229.65	4.50	14.76	12.05	39.53	
5. Tunis Canal at La Goulette	11	6.83	6.50	21.32	22	72.17								Built by the Government.
6. Bizerte Canal	5	3.10	10.00	32.80	100	328.08								Approximate length; built by the Government.
7. Manchester Canal:														
Actual condition	57	35.42	7.93	26.01	36.80	120.73	1 triple	45.75	150.09	4.88	16.01	9.15	30.01	Built by a company.
								106.75	350.22	7.68	25.19	15.25	50.03	
								183.00	600.39	8.53	27.98	24.40	80.05	
In execution	57	35.42	8.54	28.01	50-60	164.04-196.85	4 double	106.75	350.22	8.53	27.98	13.72	45.02	
								183.00	600.39			19.82	65.02	
8. Kaiser Wilhelm Canal	98	60.89	9.00-9.80	29.52-32.15	22	72.17	2 double	150.00	492.12	9.80	32.15	25.00	82.02	Built by the Government.
9. Corinth Canal	6	3.73	8.00	26.24	21	68.89								Built by a company.
10. Canal from Gand to Terneuzen:														
Actual condition	34	21.12	6.05-6.50	19.84-21.32	17	55.77	1 double	125.00	410.10	5.66	18.56	8.00	26.24	Built by Belgium and Holland.
								90.00	295.27	5.61	18.40	12.00	39.37	
In execution	34	21.12	8.05	26.41	19.50	63.97	1	140.00	459.31	7.65	25.09	15.75	51.67	
11. Canal of Bruges	11	6.83	8.00	26.24	22	72.17	1	256.00	839.89	10.00	32.80	20.00	65.61	Built by the city of Bruges.
12. Havre Canal, at Tancarville	25	15.53	6.00	19.68	19	62.33	2	180.00	590.55	6.00-7.00	19.68-22.96	18.00	59.05	Built by the Government.
13. Basse Loire Canal	15	9.32	6.00	19.68	22.25	72.99	2	120.00	393.70	6.00	19.68	18.00	59.05	Do.
14. Cronstadt Canal	27	16.78	6.70	21.98	64	209.97								Do.
15. Walcheren Canal			7.00-7.50	22.96-24.60	20	65.61								Do.
16. Königsberg Canal	33	20.50	6.50	21.32	30	98.42								Do.

-1-

St Louis Canal – France

Completed in 1871

Between the sea and the River Rhone near its mouth

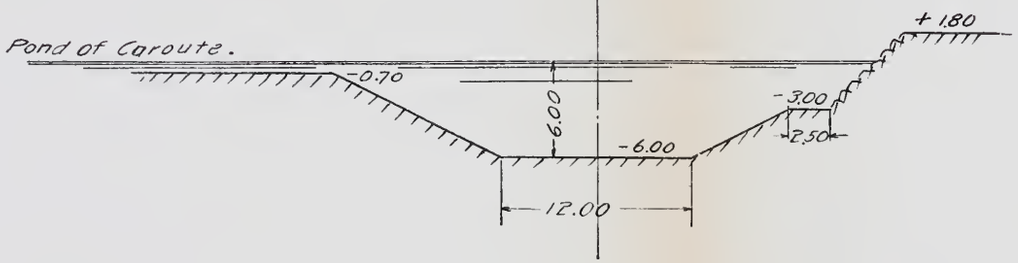


-2-

Bouc Canal at Martigues - France

Completed in 1874

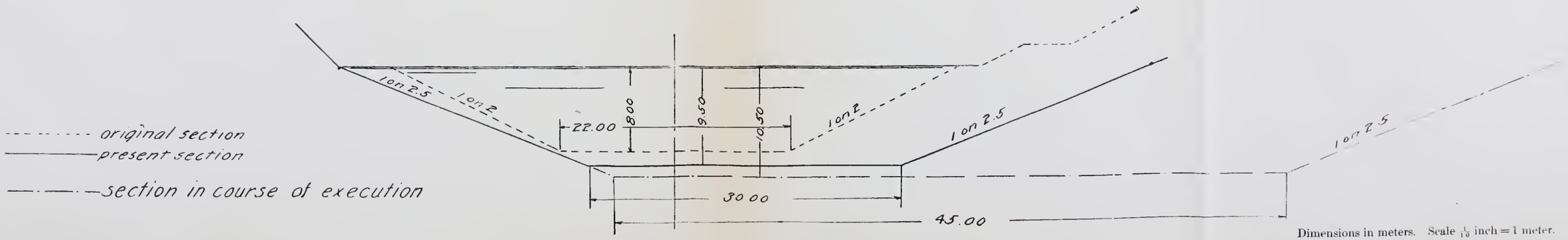
Between the sea and Pond of Berre



-3-

Suez Canal - Egypt

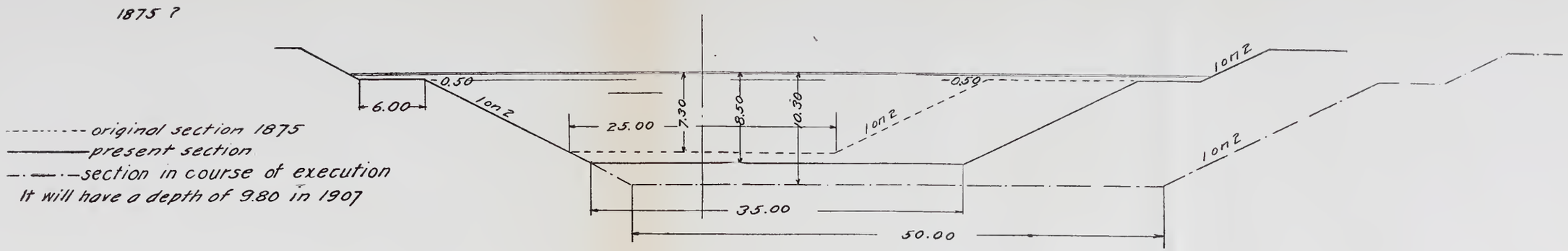
Completed in 1871



Dimensions in meters. Scale $\frac{1}{10}$ inch = 1 meter.

-4-

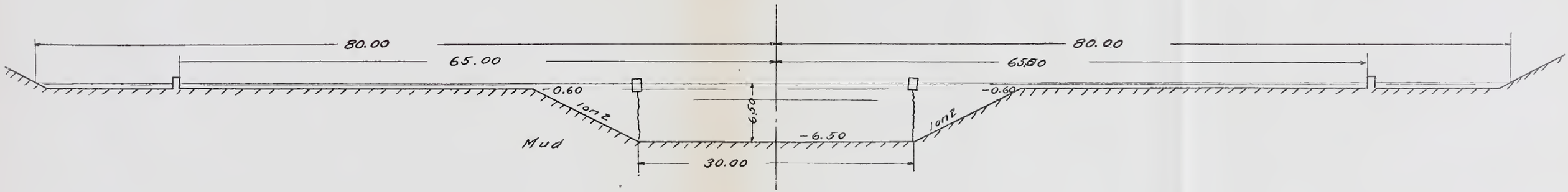
The Amsteraam Canal at the North Sea - Holland



-5-

1896 ?

Tunis Canal at La Goulette - Tunis



-6-

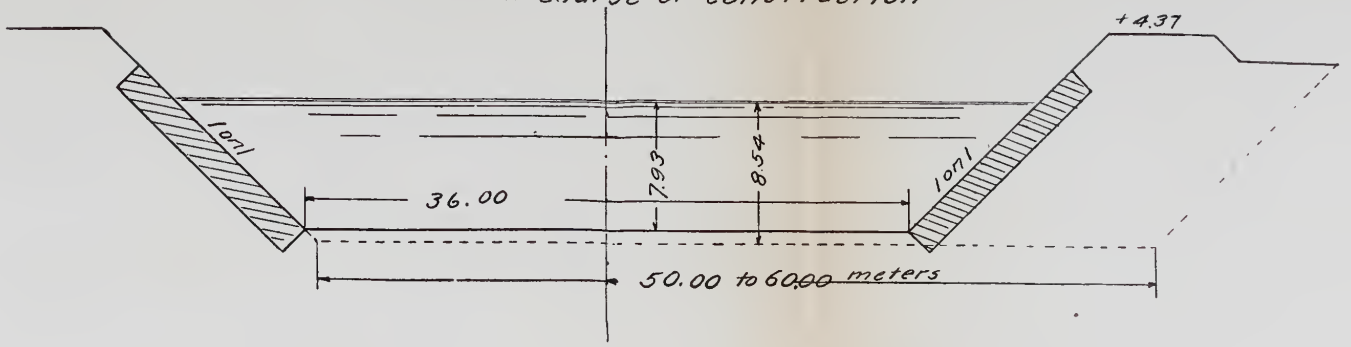
The Bizerte Canal - Tunis

Dimensions in meters. Scale $\frac{1}{10}$ inch = 1 meter.

-7-

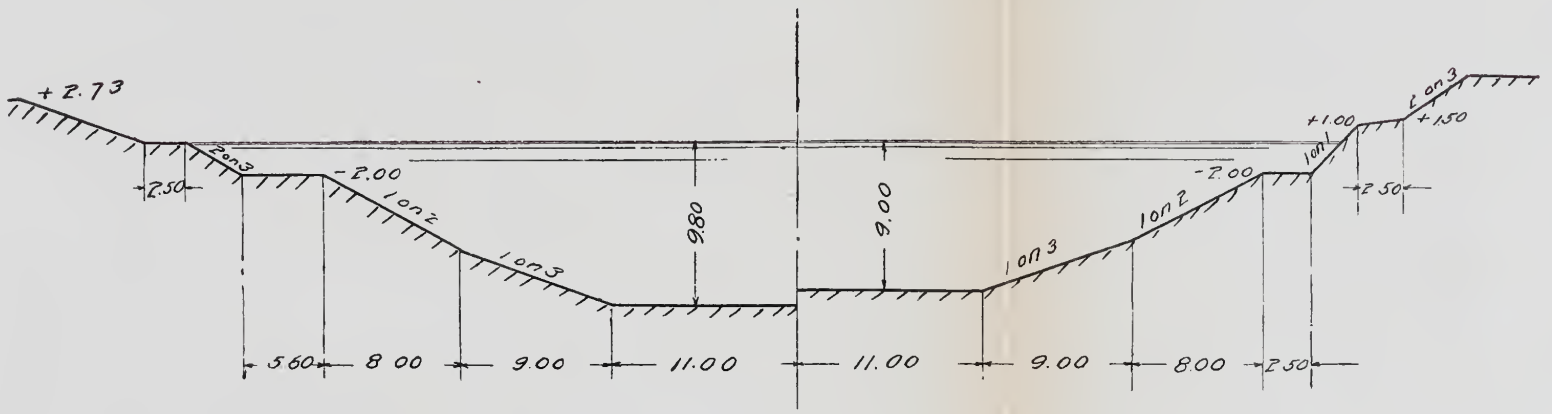
1894 Manchester Canal - England

---------- in course of construction



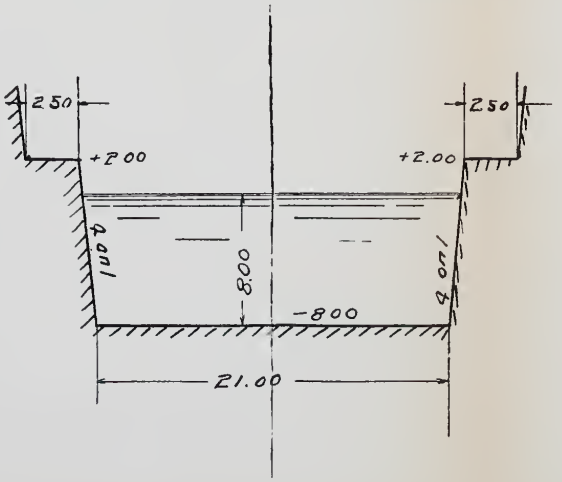
-8-

1895. Kaiser Wilhelm Canal - Germany

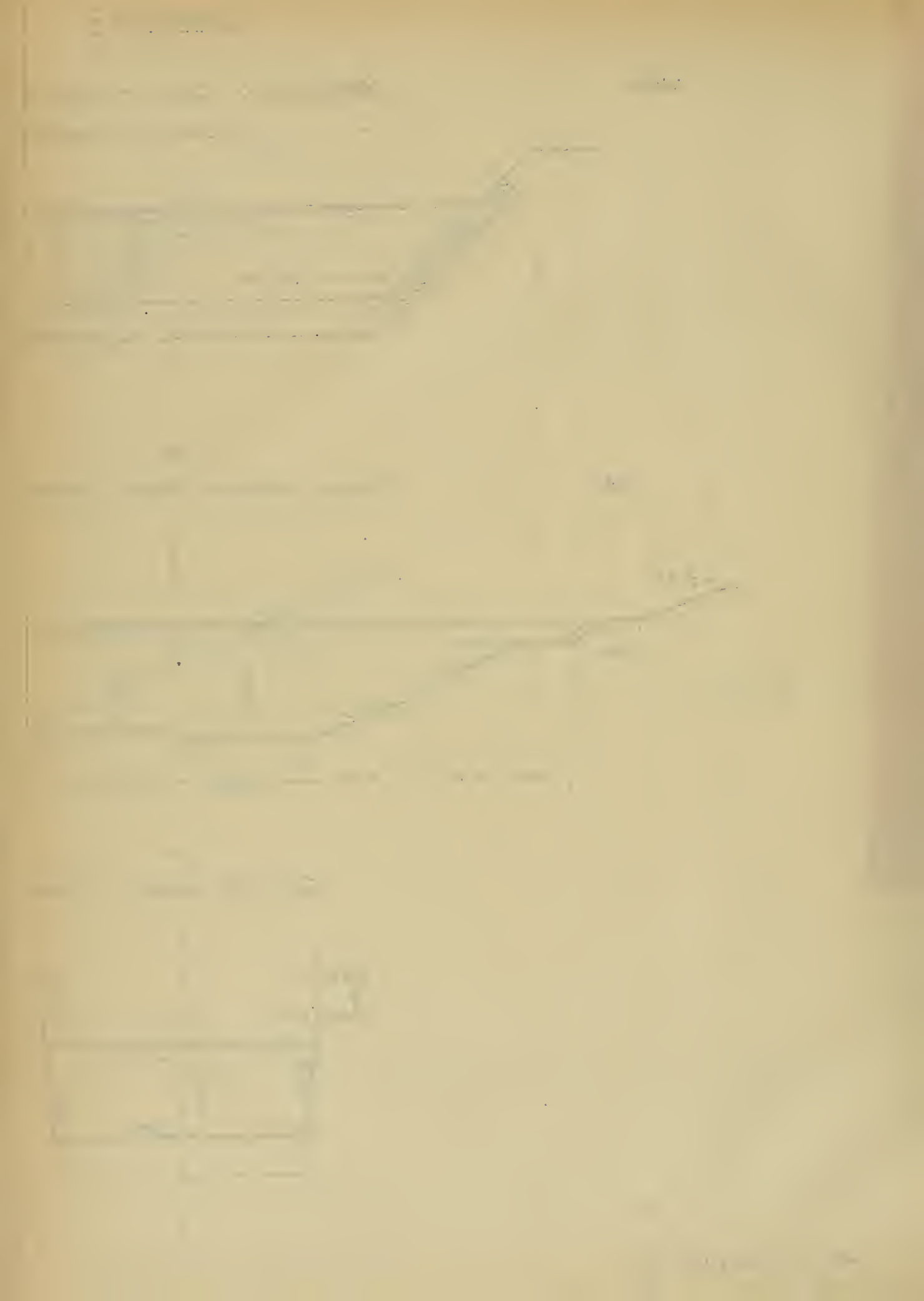


-9-

Corinth Canal - Greece

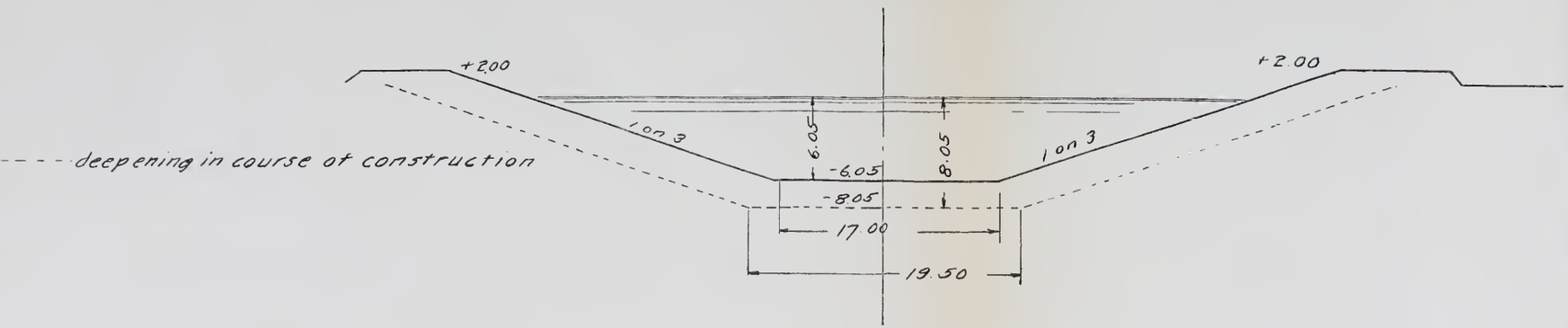


Dimensions in meters. Scale $\frac{1}{10}$ inch = 1 meter.



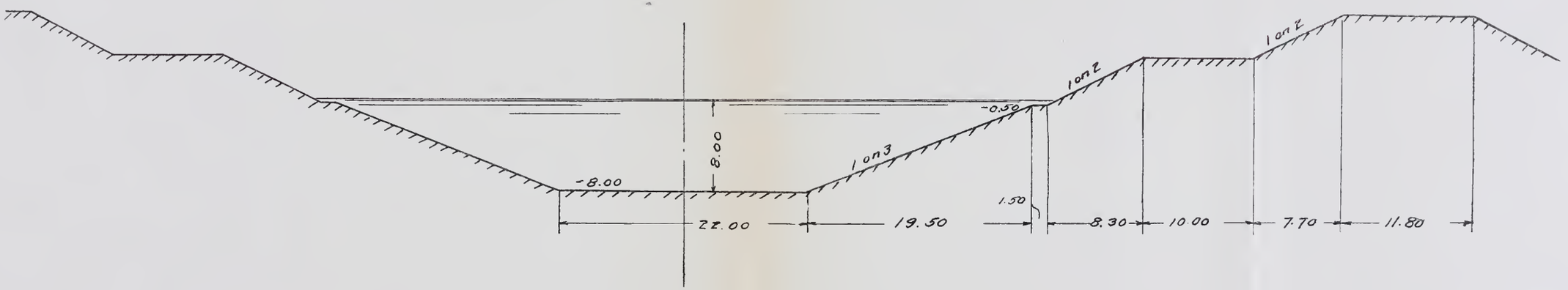
-10-

Canal from Gand to Terneuzen
Belgium and Holland



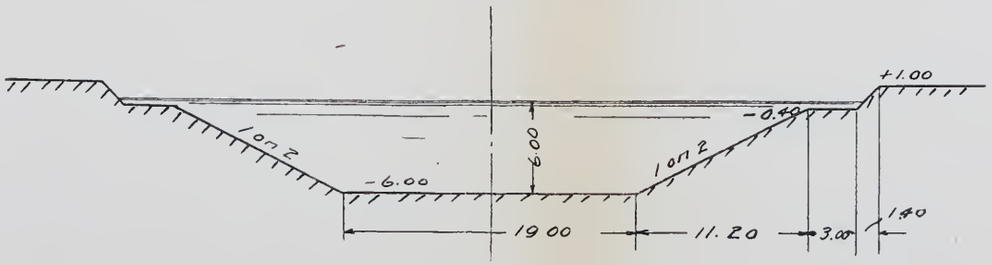
-11-

The Bruges Canal - Belgium.
1902



-12-

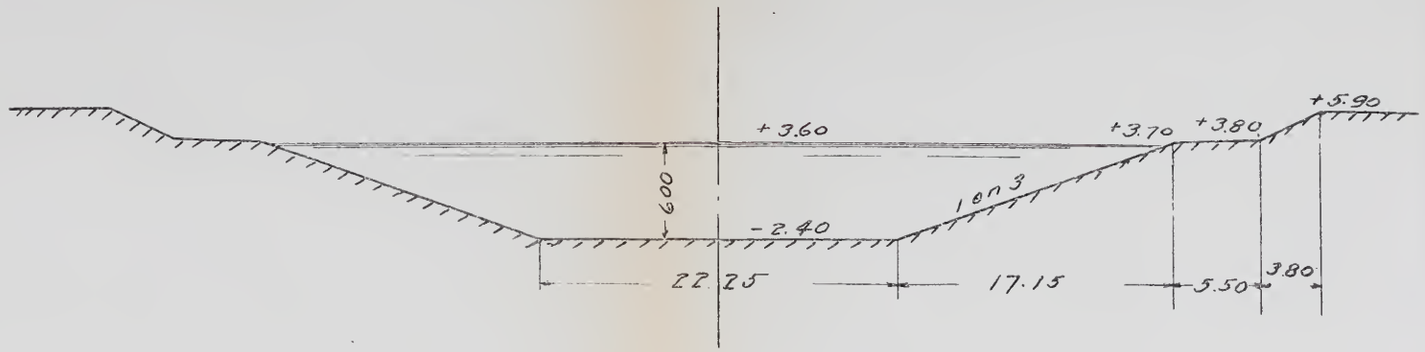
Havre Canal at Tancarville - France
Between Havre & Harfleur



Dimensions in meters. Scale $\frac{1}{10}$ inch = 1 meter.

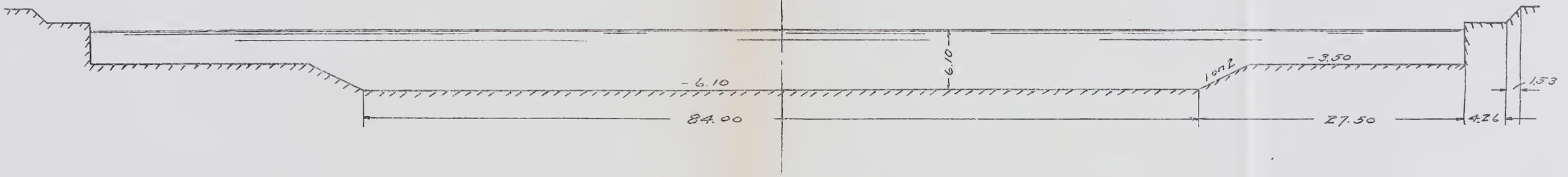
-13-

Canal of Lower Loire - France



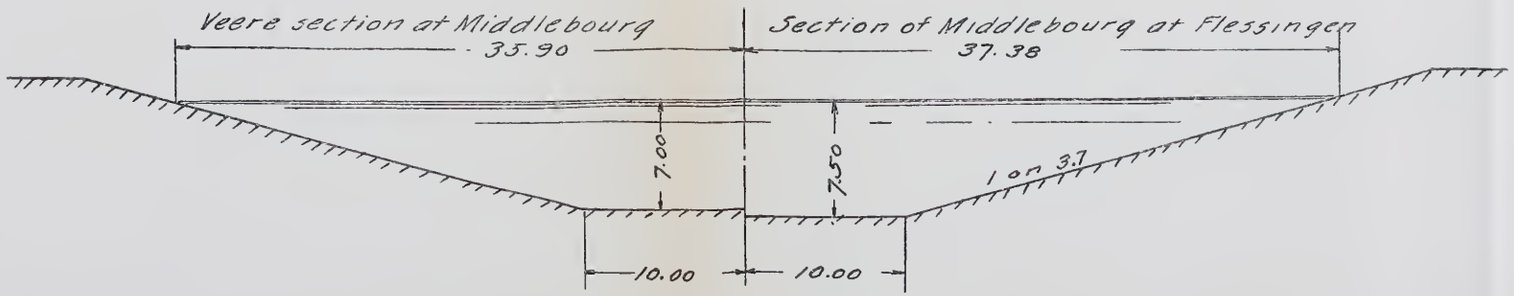
-14-

Cronstadt Canal - Russia



-15-

The Walcheren Canal - Holland & Belgium



Dimensions in meters. Scale $\frac{1}{10}$ inch = 1 meter.

Appendix E.

HYDRAULICS OF THE PANAMA CANAL.

By Henry L. Abbot.

(a) SOME OF THE HYDRAULIC PROBLEMS OF A SEA-LEVEL PANAMA CANAL.

Granting for the sake of the argument that by a dam at Gamboa, and deep cuts or tunnels to the Pacific or Atlantic, the upper Chagres River may be diverted from the canal route, although neither of these assumptions is warranted by known technical data demonstrating that the increased cost and increased time of construction would be justified, there still remain other hydraulic problems well worthy of study. These pertain to the topography of the canal route, and to the volumes contributed by streams entering below Gamboa.

TOPOGRAPHY OF THE CANAL ROUTE.

Starting from Colon the route, after traversing a swamp to kilometer 4, follows the valley of the Mindi to kilometer 6.5, and then enters the valley of the Chagres, the lowest level of which it occupies as far as Obispo, at kilometer 45. At the low stage of the river the level of the Gulf extends to Bohio, at kilometer 23.5, and all tributaries below that point would enter the canal route at levels not differing materially from that of the Gulf. At Bohio begins the anticlinal geologic arch of the Isthmus which, attaining its maximum height at the Culebra, sinks to sea level near Miraflores. Throughout this entire distance of 23 miles all streams cut by the canal would naturally enter it in the form of cascades. These streams from Bohio to Obispo are properly classified as direct tributaries of the Chagres. From Obispo the route follows to the divide at the Culebra the valley of an important tributary concerning which some confusion in name exists. The early maps designated the main stream throughout as the Obispo, but those of later date extend the name of one of its upper branches, the Camacho, from its original junction opposite kilometer 51.3 to kilometer 47, where the name Obispo is resumed. There are thus now two disconnected Obispo rivers, the upper and the lower, the confusion of name resulting from necessary artificial diversions at points where affluents entered the excavation. After passing the continental divide at the Culebra, the route follows down the valley of the Rio Grande to tide water near Miraflores, and in this section the reduced rainfall simplifies the problem.

For a proper understanding of this hydraulic problem it is desirable to know the number of tributary streams cut by the canal, and the heights of the cascades which would naturally result. This information will be found in the table following for the more important affluents, many of the smaller class being omitted.

Natural cascades into a sea-level canal.

	Kilometer.	Cascade of—		Kilometer.	Cascade of—
Valley of the Chagres, right bank:		*Feet.*	Valley of the Chagres, left bank—Continued.		*Feet.*
Quebrada Aojeta	24.6	15	Quebrada Culo Seco	38.5	40
Rio Agua Salud	26.3	25	Rio Carabali	41.0	40
Rio Frijolito	28.0	20	Rio Mandinga	45.0	45
Rio Frijoles Grande	29.0	26	Valley of the Obispo, right bank:		
Quebrada	35.2	26	Rio Sardanilla	49.0	150
Quebrada	35.4	26	Rio Masambi	51.7	195
Rio Pisco	39.0	34	Rio Obispo	52.7	195
Rio Juan Grande	40.5	38	Valley of the Obispo, left bank:		
Quebrada Cuatro Calles	43.0	45	Rio Camacho	50.0	150
Valley of the Chagres, left bank:			Valley of the Rio Grande, right bank:		
Rio Gigante	30.5	30	Rio Grande	56.0	130
Rio Caño	32.0	35	Quebrada Mallejon	59.5	33
Quebrada Agua Bendita	34.3	35	Valley of the Rio Grande, left bank:		
Quebrada Caimito Mulato	36.0	33	Rio Pedro Miguel	59.8	15
Rio Baila Monos	36.8	45	Rio Caimitillo	61.0	13

A simple inspection of this table will convince any engineer that a canal subject to such irruptions could neither be navigated by ocean shipping nor be maintained at any reasonable cost. Diversion channels over 40 miles in length, paralleling the canal and demanding heavy cuts and probably tunnels and auxiliary dams, to say nothing of levees, must be contemplated. With a summit level of 65 feet a lock canal will be subject to no such difficulties, as nearly all of the affluents will be absorbed naturally in Lake Bohio.

But to fully appreciate the problem for a sea-level canal it is also needful to form an idea of the volume to be delivered by these tributaries.

DISCHARGE OF THE TRIBUTARIES BELOW GAMBOA.

This volume naturally received considerable attention from the engineers of the old company, as they had in view the construction of a canal at sea level. The conclusions are summed up in the following table extracted from the able report of Monsieur Bérges, director of works, which bears the date of September 24, 1889. The figures are doubtless fair approximations to the truth, and all later information tends to confirm their accuracy. Thus our Isthmian Canal Commission made a few check gaugings at weekly intervals for several months, including the dry season, and the average and the largest volumes actually measured are added to the table for comparison; but of course absolute values for these quantities could only be determined by continuous gaugings covering much longer periods.

Discharges of affluents, in cubic feet per second.

Tributary.	Dry season.	Rainy season.	Freshets.	Floods.	Commission gaugings.	
					Average.	Maximum.
Agua Salud	19	198	982	2,306	33	90
Frijoles Grande	31	321	1,593	3,740	55	219
Gigante	18	185	920	2,158	65	281
Rio Caño	75	773	3,850	9,006	335	1,640
Baila Monos	15	153	760	1,775	.....	.....
Obispo (km. 45)	61	630	3,135	7,350	90	1,177
Total	219	2,260	11,238	26,335	.....	.....
Trinidad	155	1,587	10,242	18,506	1,110	2,607
Gatuncillo	137	1,377	6,850	16,100	528	1,559

After the abandonment of the idea of a sea-level canal, the individual contributions of these streams became a matter of minor importance, inasmuch as their flow would be absorbed naturally

and without inconvenience in the lake projected above Bohio; hence the new company made no elaborate individual gaugings, but in the days of the receiver some systematic measurements were made, especially on the Camacho and the Obispo opposite kilometer 47.8 (Las Cascadas), and on the Rio Grande at the dam site, use being made of the method by weir valuation at masonry barrages constructed for the purpose. The records, based on from one to three daily gaugings, began October, 1889, and continued with a few interruptions to about the date of the formation of the new company. The following table exhibits the results for the first-named streams during two continuous years, and the figures may be considered as typical for the smaller class of affluents. Evidently an insignificant tributary of the Chagres may at times deliver a formidable volume.

Discharge in cubic feet per second.

Month.	Camacho, 1892.		Camacho, 1893.		Obispo, 1892.		Obispo, 1893.	
	Average.	Maximum.	Average.	Maximum.	Average.	Maximum.	Average.	Maximum.
January	4.24	5	4.59	21	4.20	6	4.16	5
February	1.41	2	1.59	13	1.66	3	1.94	3
March	1.06	3	0.53	10	1.27	3	1.52	2
April	0.71	1	1.24	19	1.66	9	2.52	9
May	31.78	583	40.61	1,077	8.37	88	11.69	220
June	67.10	961	49.44	540	20.45	378	10.98	216
July	84.76	1,148	42.38	558	11.44	29	13.63	322
August	120.08	1,045	60.04	675	19.60	269	10.98	221
September	74.16	900	75.22	1,349	12.40	134	8.02	1,147
October	91.82	1,021	120.08	1,314	12.64	346	40.97	1,346
November	141.27	1,148	102.42	1,150	30.97	406	12.52	63
December	49.44	1,282	121.84	961	22.67	1,130	20.02	133
Year	55.65	1,282	51.67	1,349	12.28	1,130	11.58	1,346

The streams of the Rio Grande Valley, fed by a much smaller rainfall than those of the Chagres, are less subject to phenomenal freshets. The upper Rio Grande was gauged by the weir method at the dam opposite kilometer 55.5 during the three years from 1890 to 1892, giving for the mean annual discharge per second 13.03, 9.54, and 17.06 cubic feet per second, respectively. The distribution among the different months is shown in the following table:

Discharge in second-feet of the Rio Grande in 1892.

Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1.48	0.56	0.39	0.35	10.24	13.77	17.91	28.50	42.03	37.08	39.20	12.22

These facts and figures make it apparent that the problem of protecting a sea-level canal against the water courses which enter below Gamboa (assuming that the entire volume of the upper river is there diverted) lies chiefly in the district that drains to the Atlantic. The Pacific slope is easily regulated, but this is far from the case on the Atlantic side. The total volume here to be dealt with is measured by the difference in present flow past Gamboa and past Bohio. An exhaustive analysis of monthly averages covering eleven years at each of these two localities indicates the following proportions between them:

The percentage of the volume passing Bohio, which has passed Gamboa, is—

In the dry season, 86 ± 2.0
In the rainy season, 65 ± 1.6
And annually, 68 ± 1.4

In other words, it is impossible to divert more than about two-thirds of the flow of the Chagres near Bohio from the immediate canal route, and it becomes essential to know in cubic feet per second what quantities remain to be dealt with. This will next be considered, first for the ordinary freshets and then for the great floods.

VOLUME OF FRESHETS AND GREAT FLOODS.

A comparison of the difference in flow between Gamboa and Bohio for twenty-four hours, during 12 freshets occurring between August, 1899, and January, 1904, at dates when the rain records established that the downfall was well distributed throughout the valley, indicated as to be dealt with an average volume of about 5,000 second-feet, ranging as high as 12,000 second-feet. Four freshets in the same period, when the rainfall was chiefly in the upper basin, indicated an average volume of about 4,000 second-feet, ranging up to 6,000 second-feet; and three freshets with rainfall chiefly in lower basin indicated about 9,000 second-feet, ranging up to above 14,000 second-feet. These figures demonstrate that even to control what would remain, after the diversion of the upper Chagres, during ordinary freshets would call for artificial channels of no small dimensions.

The following table presents a brief résumé of what goes before, including a list of the more important affluents of the Chagres below Gamboa, arranged in the order in which they would naturally enter the canal, together with their probable individual contributions and heights of cascades, based so far as possible upon the data given above. For the upper Obispo and the Camacho the figures represent the average measured volumes during the two years 1892 and 1893; for the five streams measured by the old company the figures reported by Monsieur Berges are adopted, and for the rest estimates are formed from the comparative size of their drainage areas and their locus as to rainfall, which rapidly increases as the Gulf is approached:

Contributions of affluents below Gamboa, in second-feet.

Affluent.	Dry season.	Rainy season.	Freshets.	Cascades.	Affluent.	Dry season.	Rainy season.	Freshets.	Cascades.
Upper Obispo (km. 49)	2	16	466	165	Quebrada Agua Bendita	8	80	300	35
Rio Camacho (km. 49)	2	80	982	165	Rio Caño	75	773	3,850	33
Rio Mandinga (km. 45)	5	300	1,500	45	Rio Gigante	18	185	920	30
Quebrada Cuatra Calles	10	50	500	45	Rio Frijoles Grande	31	321	1,593	26
Rio Carabali	15	150	760	40	Rio Frijolito	20	200	1,000	20
Rio Juan Grande	15	300	1,200	38	Rio Agua Salud	19	198	982	25
Rio Pisco	15	300	1,200	34	Quebrada Aojeta	20	200	1,000	15
Quebrada Culo Seco	5	80	300	40	Total	283	3,466	17,613	.....
Rio Baila Monos	15	153	760	45	Measured total, 14 years	213	2,039	(?)	.....
Quebrada Caimito Mulato	8	80	300	35					

The "measured total" here represents the difference between the discharges carefully measured month by month for fourteen years at Gamboa and Bohio; and when it is remembered that these years cover an epoch of exceptionally low rainfall, giving a discharge much less than that in the time of the old company, the correspondence is as close as could be expected in such estimates.

Passing now to a consideration of the great floods, which really furnish the only proper standard for estimating the volumes to be dealt with, the available figures will be found in the following table:

Discharges in the great floods, in cubic feet per second.

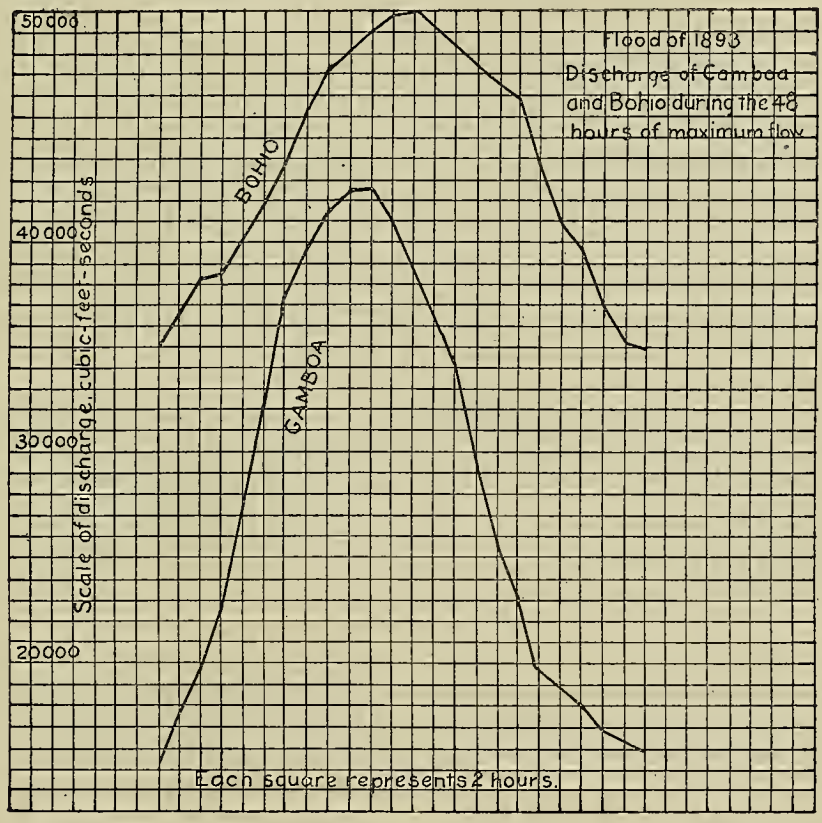
Flood.	Gamboa.		Bohio.		Excess at Bohio.	
	Maximum.	48 hours.	Maximum.	48 hours.	Maximum.	48 hours.
1893	43,000	28,000	51,000	44,000	8,000	16,000
1890	65,000	35,000	72,000	51,000	7,000	16,000
1888	58,000	48,000	79,000	(?)	21,000	(?)
November, 1885	64,000	43,000	75,000	(?)	11,000	(?)
December, 1885	45,000	32,000	47,000	(?)	2,000	(?)
1879	79,000	(?)	113,000	(?)	34,000	(?)

It is greatly to be regretted that no hourly records of water level in these floods were kept at Bohio by the engineers of the old company, but the two kept there at later dates demonstrate

that the usual river rule that the curve of hourly average of discharge per second flattens and broadens in passing from an upper to a lower station holds good for the floods of the Chagres, as it is well known to do for the larger type of its freshets. The two floods fully reported in the table indicate that this normal change of form actually doubles, during the forty-eight hours of maximum flow, the excess noted when the crest is passing. In other words, to protect a sea-level canal against the tributaries entering below Gamboa in a flood like that of 1879, the standard adopted for all lock-canal projects, it would be unwise to project artificial waterways capable of carrying to the Atlantic less than from 35,000 to 40,000 cubic feet per second during a period of forty-eight hours. To convey an idea of their dimensions it may be noted that such a volume passing through the present channel of the Chagres at Bohio, at the low-water stage, would raise the water level about 23 feet.

Perhaps the above estimate for the volume contributed by the affluents between the two stations (adopting the excess of volume when the maximum wave is passing) requires further elaboration. A flood wave passing Gamboa receives before reaching Bohio two modifications—(1) the contributions of the affluents entering between the two points, which tend to augment it; and (2) any reserves which remain behind, causing a rise in the general water level, which tend to reduce it. In a stream no wider than the Chagres this latter quantity is not important, if the flow remains within banks; but if it be sufficient to flood the neighboring valley, the modification of the flow at Bohio may be considerable. The records show that in the flood of 1893 the banks were not flooded, and it thus affords a trustworthy value of the ratio in question.

The diagram is added to illustrate the matter graphically.



The lower curve shows the flow past Gamboa at two-hour intervals during the forty-eight hours of maximum flow, and the upper curve the same quantities at Bohio. The ordinates between these curves represent the modifications in volume received between the two stations. It will be noted that these ordinates, or differences in discharge, grow smaller while the river

bed is filling and grow larger as it is emptying, thus warranting the belief that their general average truly represents the contributions of the tributaries. What is wanted in the present study is the ratio between the difference between the maximum flow at the two stations and the average of the forty-eight hourly differences, representing the volume added by the affluents. The table above shows that the latter is double the former. A comparison of the tabular volumes for the flood of 1890 gives 2.3 for this ratio, which is as it should be, since in that flood there were extensive inundations tending to increase the ratio.

But the actual conditions in the flood of 1879 would not be repeated in a similar downpour with the upper river diverted at Gamboa, because the flooding of the valley between the two stations, involving the filling and emptying of a temporary lake, would not occur. To estimate what would happen under the new conditions it would seem to be liberal and conservative to reduce by one-half the doubling ratio indicated by the two measured floods, and this has been done.

There is another independent method of checking this estimate, based on well-established facts. As stated above, eleven continuous years of records at Gamboa and Bohio demonstrate that during the rainy season the average flow past Bohio is one-third more than at Gamboa. Let us apply this rule to the two fully recorded floods of the table above:

In 1893: $3 \times 16{,}000 = 48{,}000$ to compare with 44,000 second-feet observed at Bohio.
In 1890: $3 \times 16{,}000 = 48{,}000$ to compare with 51,000 second-feet observed at Bohio.

If, then, in these two moderate floods one-third of the average volume passing at Bohio in forty-eight hours was contributed by the lower tributaries, that is to say 16,000 second-feet, it is conservative to assume that in the vastly greater flood of 1879 the actual flow past Bohio in that period was $2 \times 34{,}000 = 68{,}000$ second-feet in excess of that passing at Gamboa; and that of this, one-half had been contributed by the lower tributaries, that is to say 34,000 second-feet. One-third of the measured maximum in 1879 is 38,000 second-feet. These figures form the basis of the above estimate of the volume for which artificial channels must be prepared below Gamboa in case a sea-level construction is adopted. In view of the heavy rainfall in the district below Gamboa the figures are not unreasonable. Bohio is the point of maximum downfall on the canal route. The usual annual volume there is 146 inches, and the November volume 20 inches. At Colon these volumes are 128 inches and 21 inches, and at Gamboa, 94 inches and 12 inches.

The data at my disposal are not sufficient to warrant an attempt to prepare a detailed project for the artificial channels needful to divert the flow of the tributaries from a sea-level canal. It is apparent from an inspection of the map that one, at least, will be required on each bank, that on the left bank involving the most serious difficulties. Dams, cuts, possibly tunnels, and certainly high levees, will be unavoidable; and artificial channels subjected at times to such torrential discharges, and probably choked by tropical vegetation, can not but be a menace to the canal, which must necessarily lie between them and at a lower level in their immediate vicinity. The adjustment of the canal to the river is the fundamental problem of the route, so far as engineering conditions are concerned, and no good adjustment seems possible other than by the system of locks and dams.

CONCLUSIONS.

In fine, a project for a sea-level canal must include (1) one tidal lock at Miraflores; (2) a dam at Gamboa, where the site is so unfavorable that a masonry dam is unavoidable with foundations 50 feet below the bed of a river subject during nine months of the year to sudden freshets of 20 or more feet; (3) unless the dam be enormous, spillway cuts or long tunnels through unknown geologic formations, probably ranging from hard igneous rock to uncertain sedimentary deposits, and demanding an aggregate cross section larger, by far, than the new double-track railroad tunnel under the Alps; and (4) over 40 miles of artificial and very costly diversion channels for tributaries entering below Gamboa, which channels must lie in the immediate vicinity and be a menace to the canal. All these items must be added to the huge excavation through the continental divide, which of itself proved so disastrous to the old canal company.

Until very recently the idea of a sea-level construction has been definitely abandoned. The Isthmian Canal Commission of 1899–1901 reported:

The cost of such a canal, including a dam at Alhajuela and a tide lock at Miraflores, near the Pacific end, is estimated at not less than $240,000,000. Its construction would probably take at least twenty years. This Commission concurs with the various French commissions which have preceded it since the failure of the old company in rejecting the sea-level plan. While such a plan would be physically practicable, and might be adopted if no other solution were available, the difficulties of all kinds, and especially those of time and cost, would be so great that a canal with a summit level reached by locks is to be preferred.

The International Commission of Engineers, advisory to the new canal company, in 1898, thus expressed its views as to a sea-level project:

It is not possible to think of utilizing the river itself for the passage of shipping, by rectifications studied with this end in view; the irregularity of its flow and the violence of its floods are incompatible with a solution of this kind. The complete diversion of its course to the Pacific, far from the route of the canal, as was formerly suggested and in part studied, would be a colossal undertaking which it does not seem possible to adopt. Hence it is necessary to accommodate the character and needs of the river and canal to those of near neighbors, which it is very difficult to do in the case of a sea-level canal. Even if the outflow of a large part of the drainage basin were confined in temporary reservoirs, it must be recognized that it is necessary to provide for the river, by the side of the canal, an artificial bed capable of carrying a very considerable volume in certain flood conditions. An artificial bed prepared above the level of the canal, which could carry so large a flow, would represent a work not only very difficult to practically accomplish, but also one which must be a permanent menace to the canal. Thus it may be said that the principal obstacle to the realization of a sea-level canal arises less from the difficulties inherent to the execution of the grand cut at the continental divide than from those caused by the presence of the Chagres in the district which must be crossed before reaching this divide, and that it perhaps would be not too much to insist that here is an insurmountable obstacle to such a conception.

These views were by no means confined to the engineers of the technical commission. Thus the eminent chief engineer of the new company, Monsieur Choron, in commenting upon a paper read before the Institution of Civil Engineers, in London in 1901, remarked:

The paper gave a clear account of the present position of the matter from a technical point of view. The author was not correct, however, in stating that the technical commission's principal reason for putting aside the plan for a sea-level canal had been its cost and the impossibility of its yielding a profit as a commercial scheme. The reason had not been the cost, which, perhaps, might not be a much more important matter than in the case of the plan adopted, but the grave technical difficulties presented by the problem of regulating the Chagres River and protecting the canal against its floods. With a lock canal and the great central lake of Bohio, this problem admitted of easy solution; without that lake it was almost insoluble. Hence the author's view, that the nearer a lock canal approached to the sea-level the better it would be, was not altogether justified, because really the inherent difficulty of the regulation of the Chagres River would be seriously increased by lowering the level of the lake of Bohio below that adopted by the technical commission.

The idea conveyed by the last sentence will be appreciated from an inspection of the first of the foregoing tables, showing the heights of the natural cascades at the mouths of the tributaries, all of which, at and below Obispo, are eliminated by a Lake Bohio at the summit level (65 feet) favored by the technical commission.

In fine, it is my personal belief that to adopt a sea-level project would be not only to deprive the present generation of business men of all benefits to result from the opening of an isthmian canal to commercial enterprise, but also to involve the Government in expenditures too enormous to be justifiable. To double the necessary time and expense of construction without materially improving the canal is certainly not wise; and the passage of a few modern locks is far less objectionable than to incur the risks of delays and accidents inherent in a regulation of the Chagres based on its total diversion *below* as well as *above* Gamboa, and this is unavoidable with a construction at sea level. The river is transformed from a friend into a formidable enemy.

(*b*) WATER SUPPLY OF THE CANAL FOR THREE VARIANTS, ASSUMING A LAKE AT GATUN RAISED TO ELEVATIONS 85 FEET, 60 FEET, AND 30 FEET, THE LATTER COMBINED WITH A LAKE AT BOHIO RAISED TO ELEVATION 60 FEET.

The first point to consider is what is known as to the fundamental elements of the problem.

FLOW OF THE RIVERS.

As will be seen farther on, it is only during the months of February, March, and April that there can be any serious question of water supply for operating a canal with locks, the daily flow of the streams amply providing for any demands during the rest of the year. The run-off at Bohio during the dry season, in cubic feet per second, is known for fifteen years, the average volume being 1,371 second-feet and the minimum being 742 second-feet, the latter occurring in 1903. In like manner the average yearly run-off at Bohio is known for fourteen years, the volume averaging 4,798 second-feet, with a minimum of 3,384 second-feet, which occurred in 1899. The area of the basin above Bohio is about 700 square miles. The ratio between rainfall and run-off in this basin was carefully measured for six years, and was found to be 0.66 annually, the observed annual run-off being 73.44 inch-miles and the observed annual rainfall being 111.54 inches.

The Isthmian Canal Commission of 1899–1901 gauged the Gatuncillo River for twenty days in February, March, and April, 1900, and the Trinidad River for eighteen days in the same months. The average volume of the former was 156 second-feet and of the latter 319 second-feet, giving, for the two, 475 second-feet. Very fortunately this was a year of nearly minimum discharge, the 15 yearly gaugings at Bohio showing that only in 1901 and 1903 was a less volume noted. The latter at Bohio was the year of absolute minimum flow in the dry season (742 cubic feet per second), and in 1900 the volume was only 11 per cent more. Moreover, as the rain records show that the downfall in the basin below Bohio in these months was about 17 per cent greater in 1903 than in 1900 (3.86 and 3.30 in.), it is certain that these gaugings give what may be confidently assumed as the extreme low-water contributions of the Gatuncillo and Trinidad rivers. They are therefore very useful in the problem under consideration.

Thus we have for the minimum dry season contributions of the Chagres above Gatun:

	Second-feet.
Chagres above Bohio	742
Gatuncillo	156
Trinidad	319
Other small brooks, say	8
Total	1,225

Furthermore, assuming that the average low-water flow of the river at Gatun bears the same proportion to the minimum as at Bohio, we may conclude that this average low-water volume at Gatun is 2,270 second-feet.

As no annual gaugings of the Gatuncillo and Trinidad have ever been made, the most direct determination of the average annual flow past Gatun is to assume the same ratio between rainfall and run-off in the basin below Bohio as is known to hold in the basin above Bohio, which, as stated above, is 0.66. The average annual rainfall at Colon and at Bohio is known for many years, and the mean, or 137.2 inches, will fairly represent the downfall to be expected in the basin of the Chagres below Bohio. Based on this figure the computation indicates 8,120 second-feet as the average annual flow of the entire basin above Gatun. Assuming the same ratio between the average and minimum annual flow as exists at Bohio, the latter at Gatun is 5,660 cubic feet per second.

The average flow in January and May, although less, does not differ materially from that of the other seven rainy months (at Bohio as 4,206 to 6,436), but to guard against all contingencies it is not without interest to consider what might happen if the demands for lockage should exceed the contributions of the river in January and May as well as in the three dry months.

The Isthmian Canal Commission of 1889–1901 gauged the Gatuncillo and Trinidad in January and May, 1900, yielding for the former stream (8 gaugings) 207 second-feet, and for the Trinidad (15 gaugings) 608 second-feet, or jointly 815 second-feet, the corresponding volume measured at Bohio being 1,872 second-feet. These gaugings indicate for the minimum flow at Gatun in the five months in 1900 a volume of 2,687 cubic feet per second; no contributions from the small tributaries below Bohio are added, as the rain records for this basin during these five months show a slightly less downfall in 1903 than in 1900. Adopting the Bohio ratio between the minimum and average flow in these five months, the latter is shown to be 6,203 cubic feet per second. That this greatly exceeds any possible demand appears from the following considerations:

It will be shown below that the maximum demand for reserves for a traffic of about 10 million tons annually, with locks equipped with interior gates, will be 1,871 cubic feet per second, and for a traffic of about 35 million tons, 2,759 cubic feet per second. Without such gates the figures will be 2,122 and 3,492 cubic feet, respectively. On page 167 of Part II of the documents supplied to the Board will be found a table giving the monthly volume carried past Bohio for fourteen years. As the flow at Bohio is about six-tenths of that at Gatun, the volumes at the former to compare with the above figures are 1,125, 1,643, 1,257, and 2,095, respectively. It will be found that in no single rainy month did the measured flow fall below that requisite for a traffic of 10 million tons. Even for 35 million tons, using the interior gates, there would have been shortages only in three of the fourteen years, amounting to 28, 32, and 4 cubic feet, respectively, and these are more than covered by the safety coefficient of about 10 per cent used in computing the gaugings. Without interior gates the shortages would have been larger, but this only proves the necessity of introducing them.

It is very desirable to form a closely approximate idea as to the entire area of the basin above Gatun, with a view to check the above estimates for the low-water supply of the canal. The bounding crest of the Gatuncillo basin is laid down with precision on the best map extant, and I have carefully computed the area, finding it to be 158 square miles. Unfortunately the crest of the Trinidad basin is not known, but it would seem probable that the area may be closely inferred from the known low-water discharges of the Gatuncillo and Trinidad and the known area of the basin of the former. To verify the idea I computed the area of the Gatuncillo basin by assuming it to bear the same proportion to that of the Chagres above Bohio as exists between their low-water discharges. The result indicated an area of 150 square miles, differing only 8 miles from that shown by the map. Applying the same computation to the Gatuncillo and Trinidad rivers, an area of 320 square miles is indicated for the latter. The following table, therefore, indicates the figures for the entire basin of the Chagres above Gatun:

Area of the basin above Gatun.

	Square miles.
Basin above Alhajuela	320
Basin, Alhajuela-Gamboa	130
Basin, Gamboa-Bohio	250
Basin of Gatuncillo	158
Basin of Trinidad	320
Other small basins, say	22
The Chagres above Gatun	1,200

Assuming that the minimum and average flow past Gatun and past Bohio, both in the dry season and annually, are proportional to the areas of the respective basins—that is, to 1,200 and 700, respectively—a direct check is afforded upon the values deduced above based on the known discharges. The table following compares the indications given by the two methods of computation:

Critical discharges at Gatun in cubic feet per second.

Computed by—	Low-water season.		Annual.	
	Minimum.	Average.	Minimum.	Average.
Discharge	1,225	2,270	5,680	8,120
Area	1,271	2,350	5,801	8,225
Means	1,248	2,360	5,730	8,173

It would seem from this comparison that a minimum contribution of 1,250 cubic feet per second during the three dry months and a minimum annual contribution of 5,730 cubic feet per second may confidently be expected from the Chagres and its tributaries if the lower dam be placed at Gatun.

REQUIREMENTS FOR LOCKAGES.

The dimensions of the locks have been determined by the Board as follows: Depth 40 feet, width 100 feet, serviceable length 1,000 feet. The latter calls for a length of 1,065 feet in lockage computations. With a dam at Gatun raising the lake level to 85 feet, three locks in flight are required; with a 60-foot level there will be only two. In the former case the lifts will be 29 feet on the Atlantic slope and 32 feet on the Pacific.

Introducing these figures in the usual lockage formula $\frac{N+2}{4}$ V, and assuming for the triple flight at Gatun, since there are twin locks, that good regulation of the passage of vessels there will reduce the coefficient from 1.25 to 1.08, we find for the largest lockage prism on the Atlantic slope 3,540,000 cubic feet, and on the Pacific slope 3,408,000 cubic feet, demanding for one transit of the canal 6,748,000 cubic feet.

Assuming that for economy in water at the passage of smaller vessels an intermediate gate is introduced where needful to that end, and that the reduced chamber thus formed has a length between quoins of 600 feet, giving a serviceable length of 550 feet, the following reduced lockage prisms result when the summit level is at elevation 60 feet: On the Atlantic slope 1,740,000 cubic feet and on the Pacific slope 1,920,000 cubic feet, demanding for one transit of the canal 3,660,000 cubic feet. The same figures may be used, even with the flight of three locks at Gatun, if the reduced chambers be placed at the lower end of the upper lock and at the upper end of the middle lock, even with no extra gate in the lower lock, because the water prism discharged into the large lower chamber will still leave 25.85 feet over the lower wall of the middle lock, which is ample to accommodate the usual class of vessels navigating the canal.

Allowing ten daily lockages on each slope for three hundred and twenty days during the year, and assuming the average tonnage of the vessels to be 3,000 tons, a traffic of 10 million tons will be accommodated. This will call for a continuous flow of 685 cubic feet per second if only the large chamber be used. If it be assumed that eight-tenths of the vessels can be passed through the reduced chambers, which considering the dimensions of commercial shipping seems altogether probable, this figure becomes 434 second-feet.

Thirty daily lockages for three hundred and twenty days in the year, which would probably correspond to a traffic of 35 million tons, in view of the rapid increase in dimensions of shipping and the number of years that will elapse before such demands can be anticipated for the canal, would raise these figures to 2,055 second-feet and 1,302 second-feet, respectively.

OTHER LOSSES OF WATER.

Coming now to other losses of water, evaporation first claims attention. The surface of the lake above Bohio at elevation 85 feet is known to be 38.5 square miles, and at elevation 60 feet, 23.5 square miles. The areas flooded below Bohio by a lake at these elevations can only be roughly estimated, since no contours have been run in this region. From a few known points, and from approximate information received from engineers who have been over parts of the ground, the total flooded area at elevation 85 feet has been estimated at 110 square miles

(including the area above Bohio), but it must be admitted that this is little better than a guess, to be revised when the contours are definitely known. To this must be added the area of water surface of the canal beyond the lake, which may be estimated at about a mile.

Evaporation was estimated at 0.24 inch per twenty-four hours by the Comité Technique and at 0.20 inch by the Commission of 1899–1901. The former added an equal amount to cover possible losses by infiltration. Considering the uncertain data as to lake area below Bohio, it would seem to be conservative to adopt 0.24 inch to cover the losses by evaporation. This figure calls for a continuous flow of 710 cubic feet per second. Add for infiltration, say, 77 second-feet.

To cover leakages at gates the Comité Technique adopted 106 cubic feet per second, the pattern being of the single-leaf type. The Commission preferred the miter pattern, and estimated the leakage at 250 cubic feet per second. As ours are to be of the latter type, and considerably larger, it would seem that at least 250 feet should be adopted.

For lighting and motive power, and false maneuvers, the Comité Technique estimated 318 cubic feet and the Commission 200 cubic feet. The latter would seem to be conservative. The above figures are summed up in the following table, showing the requirements for a traffic of about 10 million and about 35 million tons annually.

Volume, in second-feet, for operating the canal.

Requirements.	Ten daily transits, using lock chambers.		Thirty daily transits, using lock chambers.	
	Both.	Larger.	Both.	Larger.
For lockages	434	685	1,302	2,055
Leakages at gates	250	250	250	250
Evaporation	710	710	710	710
Infiltration	77	77	77	77
Lighting, power, etc	200	200	200	200
Contingencies	200	200	200	200
Total	1,871	2,122	2,739	3,492

VOLUME OF WATER RESERVES.

Considering first the two variants based on summit levels of 85 and 60 feet elevation and a single lake at Gatun, and comparing the above figures with the estimated minimum flow of the Chagres at Gatun in the three dry months, it will be seen that the two modes of passing vessels (using both chambers or only the large chamber) will demand, respectively, 623 and 874 cubic feet per second to be held in reserve for 10 daily passages. The former volume amounts in the three months to 4,844,548,000 cubic feet and the latter to 6,796,224,000 cubic feet. In cubic meters they are about 137 millions and 193 millions. The proposed reserves of the New Panama Canal Company were 170 millions and of the Commission of 1899–1901, 104 millions.

For the larger traffic, demanding 30 daily transits, the reserved volumes are 1,491 or 2,244 cubic feet per second, depending on whether both chambers or only the larger are in use. The former volume amounts to 11,594,016,000 cubic feet, and the latter to 17,499,344,000 cubic feet. In cubic meters these figures are 328 and 494 millions, respectively. The corresponding volume, with less traffic and smaller locks, was estimated by the Comité Technique at 232 million cubic meters.

Finally, if the annual traffic should ever exceed all estimations of the present day, it is not without interest to consider how many daily transits during three hundred and twenty days of the year could be supplied by the river if its minimum annual discharge were held in reserve for the purpose. This volume at Gatun being 5,730 cubic feet per second, even if the large lock chambers only were in use, it would supply water for 63 daily transits of the canal. In other words, the Chagres River can be made to amply meet all possible demands of a lock canal, the only question to consider being the location and height of the dams.

Next considering the variant of the canal with a lake at Gatun raised to a level of about 30 feet and a lake at Bohio raised to a level of about 60 feet, the only changes in the above figures will result from the fact that the lake below Bohio will no longer be available for storage, and the contributions of the Gatuncillo and Trinidad will be wasted. On the other hand the evaporation in the lake below Bohio will not appear among the losses. The figures to be used therefore become:

Critical discharges at Bohio, in second-feet.

	Low-water season.		Annual.	
	Minimum.	Average.	Minimum.	Average.
Volume measured 14 years	742	1,371	3,384	4,798

The losses by evaporation, estimated as above, are 158 cubic feet per second instead of 710 cubic feet, making the estimated volume required for operating the canal:

	Second-feet.
With 10 daily transits, both chambers	1,262
With 10 daily transits, larger only	1,513
With 30 daily transits, both chambers	2,130
With 30 daily transits, larger only	2,883

Discussed in the same manner as were the other two projects, these figures show for the volumes to be held in reserve for the needs of the low-water season of ninety days, 520 second-feet, 771 second-feet, 1,388 second-feet, and 2,141 second-feet, respectively. The corresponding volumes in cubic feet are: 4,045,000,000 and 5,990,000,000 and 10,800,000,000 and 16,650,000,000, respectively.

Referring to the table of monthly discharges it will be seen that all requirements for 10 daily transits would be amply met by these reserves and the natural flow of the river, as would also those for the 30 transits in the average year, but in 1903, which was exceptionally dry (lowest in fourteen measured years), it would have been needful to include January and May among months demanding reserves. The minimum flow for one hundred and fifty days would have been 1,074 cubic feet per second (instead of 742 for thirty days), calling for a volume of 13,920,000,000 cubic feet to be held back. This would have considerably more than met the needs of the larger traffic, provided use were made of both lock chambers, thus again pointing to the necessity for interior gates. Evidently the need of increasing the low-water reserves for other than the three dry months will not present itself for many years, and may then be easily met, as will appear farther on.

STORAGE OF THE RESERVES.

With a dam at Gatun raising the lake level to elevation 85 feet, the surface would be about 3,100 million square feet; at an elevation of 60 feet it would be about 2,700 million square feet; the portion above Bohio at 60 feet elevation would be about 683 million square feet. The latter is accurately known. As already stated the area of the larger lake is only an approximate estimate to be revised when the contours have been run, but it is believed to be conservative. The area is so large that the greater part of the reserves can be accommodated in the lake itself, as appears from the following figures, giving the elevations of lake surface called for to accommodate them under the different suppositions as to the volume and regulation of traffic:

	Ten daily transits.		Thirty daily transits.	
	Elevation 85.	Elevation 60.	Elevation 85.	Elevation 60.
	Feet.	*Feet.*	*Feet.*	*Feet.*
Using both chambers	1.6	1.8	3.7	4.3
Using larger only	2.2	2.5	5.6	6.5

It is proposed to limit the oscillation of the lake for storage purposes to 3 feet, thus calling for no upper lake until the increasing demands of the traffic require it. Two feet more will regulate the floods, since the spillway discharges directly into the ocean.

With the third variant (low dam at Gatun) an upper lake would be required, as appears from the following figures for lake oscillation without it:

	Feet.
For 10 daily transits, using both chambers	5.9
For 30 daily transits, using both chambers	15.8

Adopting 3 feet as the permissible oscillation of Lake Bohio for low-water reserves, and 2 feet for flood regulation, as for the 85-foot and 60-foot variants, and noting that the entire capacity of a lake at Alhajuela is available for low-water reserves, since the Lake Bohio spillway discharges into the lake below and thence directly into the ocean, the volume to be stored above is readily computed. For the 35-million ton traffic, or 30 daily transits, using both lock chambers, it is 8,751,000,000 cubic feet. This is 250 million cubic meters, and the capacity of Lake Alhajuela was to be 320 million by the plans of the new company. In other words, the Chagres could be regulated by this variant with an upper lake considerably smaller than was projected by the Comité Technique, but a better alternative would be to leave the dam unchanged and thus still further reduce the Lake Bohio oscillation. As stated above, its extreme limit fixed for all three variants is 5 feet. In the project of the Comité Technique it was 5.7 feet, and in that of the Commission of 1899–1901 it was 10.4 feet. The smaller it is the better for operating the canal.

Appendix F.

PROJECT OF MR. P. BUNAU-VARILLA.

Mr. Chairman and gentlemen, I appreciate fully the honor of being called upon to explain my views on the solution of the problem of the Panama Canal construction before a body formed of the most eminent engineers of the great nations of the world.

I have desired many years the moment which comes to-day, and I am happy to plead before this high technical court for what I think will afford a simultaneous satisfaction to all the enormous interests involved in the great interoceanic highway.

First Part.

GENERAL CONDITIONS—FUTURE NECESSITY OF A SEA-LEVEL CANAL.

Before going into the description of the solutions which I have to present, allow me first to cast a general glance at the Panama problem in order to determine its dominating factors.

Anyone looking into the probable future of the Panama traffic through the minimizing glasses of actual statistics can not fail to be struck with the probable prodigious importance of the future transit.

If five or six million tons, as statistics prove, are already actually ready to pass, what will the tonnage become when the American population settled between the Rocky Mountains and the Pacific, which now amounts to about four million inhabitants only, becomes thirty or forty millions?

What will the traffic become when the population of the Far East, one-third of humanity, awake from their long sleep and put themselves into close commercial connection with the rich, productive, industrial part of the Atlantic side of America?

Certainly such considerations will appear chimerical to those only who can not conceive for the development of the traffic more than an annual increase of 4 or 5 per cent.

Let them look at the traffic of the Sault Ste. Marie canals (American and Canadian) thirty-six years ago, when the Suez Canal was opened, and see what it has reached now. In this short period of time it has passed from a little more than half a million tons in 1869 to nearly thirty-five million tons in 1903,[a] and this with an interruption of navigation by the ice during one-third of the year.

The people who think that the traffic reached by the Suez Canal after thirty years of operation (10,000,000 tons) represents an amount which can only be reached at Panama in a distant future, may also usefully look back at the traffic passing at Detroit between Lake St. Clair and Lake Erie, and which is about twice as great as the enormous traffic of American and Canadian Sault Ste. Marie canals between Lake Superior and Lake Huron.

It is with these figures in mind, and not with the Suez Canal figures, that the future of the Panama traffic must be considered, because the Panama Canal has before itself sources of activity which are similar to the sources of the American interior canals, and not those of the canal uniting Europe and Asia.

[a] The probable traffic for 1905 is rated at about 44,000,000 tons, according to press informations.

These considerations lead us to think that a day will come when the Panama Canal will imperatively require the only form which fits the enormous trade it will carry—the sea-level form.

The Isthmian Canal Commission, after its exhaustive studies on the various different water routes through Central America, reported that the limit of the natural water supply for the operation of the lock canal proposed corresponded to a traffic of forty million tons.

Of course, one might increase this limit by resorting to pumping from the sea-level sections into the summit level, but this would be a provisional remedy and not a definitive solution.

Any lock canal at Panama will be only a temporary solution, however high or however low may be the level adopted for the summit channel, and it is impossible logically to adopt locks if we have not at our disposition the secure and certain means of later transforming the canal thus built into a sea-level canal, because that is the final and necessary form the great international waterway must take.

NATURE OF THE DIFFICULTIES WHICH PREVENT THE IMMEDIATE SEA-LEVEL CANAL CONSTRUCTION.

In order to see the problem of the Panama Canal in its true light—to find and determine the just principles which must govern its construction—it is of the highest importance to look for the real and essential causes which have attended in the past the failure of the immediate sea-level canal construction.

These causes have been generally attributed to the difficult solution of two technical problems—the control of the Chagres floods and the excavation of the Culebra cut.

Nothing is more erroneous, nothing has more often misled the most distinguished minds. The problem of the Chagres is a comparatively easy one to deal with; it can be solved theoretically and practically in different ways. I shall later on explain what I think to be the simplest and cheapest method.

The problem of the Culebra cut, however great is the mass of earth to be excavated, would not be beyond the reach of a reasonable and practical programme of execution within a period of about ten years if the work had to be executed in North America or in Europe.

It is not, therefore, in the violence of the Chagres floods, nor in the abnormal and exceptional greatness of the Culebra cut, nor in the constitution of its internal elements, that the great difficulty lies. It lies outside of conditions usually considered by engineers in dealing with great technical problems; it lies in special elements which seem to be more of a psychological nature than of a technical character.

It results essentially from the depressing influence of a damp and hot climate on the white man; it results also from the low quality of the only labor which can be employed on the Isthmus, viz, colored labor.

The Isthmus of Panama is a country where the preservation of human life seems to depend entirely upon the restricted expense of physical energy. No white man living there for months can boast of preserving his physical integrity. It is a country where the physical strain attending the leadership of great public works (I speak for those at the top as well as for those at the foot of the hierarchical ladder) is incompatible with the exigencies of nature under the depressing influence of the climate. The relaxed vigilance which results from such influence among the officers of the army of laborers is not counterbalanced, but, on the contrary, its evil consequences are much increased by the natural dispositions of its soldiers.

Where we find in our climates intelligence, foresight, vigilant and manly care in the most common white laborers, we find there among the blacks only indifference, lack of mental energy, and natural tendency to laziness. It is impossible to think a moment of employing white labor; this would mean death in a short time. No workman requires more guidance and supervision than the colored workman; nowhere is this guidance naturally more relaxed than on the Isthmus of Panama.

From the association of these two characteristic influences of the climate results an extraordinary fall in the output that is expected from any plan of action based on the knowledge acquired in the temperate zone of the earth. Equally misleading are the tentative experiments made on the Isthmus and the coefficients obtained from the work of a limited number of machines.

During these experiments there is a temporary moral stimulation of the workmen, which strains the energies and raises them more or less to the level we are familiar with, but this is only a temporary and local result. It is highly dangerous, because deductions may be drawn from the coefficients thus obtained and delays calculated upon seemingly practical experiments, but which are really not so, because the conditions under which they are made, however natural they seem to be, are really artificial and temporary. They correspond to an exceptional mental voltage which is far above the average one.

It can be said that great undertakings of public works result from the cooperation of men and machines, of brains and steel.

What would be expected from works undertaken under a hypothetic climate which, while respecting the integrity of men, would affect that of the machines; while maintaining the brains in their normal conditions, would decrease the hardness of steel and transform it into a softer metal, into a substance halfway between lead and iron?

Nobody would expect that plans calculated under the conditions existing in our own countries would ever be consummated under the influence of this hypothetic climate, capable of destroying the hardness of the steel. This is what happens in Panama, not with machines, but with men; not with steel, but with brains; and it is the most preponderous element of the whole problem.

You will excuse me, gentlemen, for insisting so long on this point, but it can never receive sufficient prominence, if one cares to know the controlling factor of any plan of action for the construction of the canal. It is the essential, the vital principle that must be constantly kept in view in the examination of all systems proposed.

SOURCES OF REALLY PRACTICAL COEFFICIENTS FOR THE CALCULATION OF TIME OF CONSTRUCTION.

As a result of what I have just said, the formation of correct ideas about the possible efficiency of any plan of action can not result from local experiments on a small scale, nor from what is customary in other lands.

If we were at the beginning of the first attempt to dig the canal we would be in the dark, and no preliminary study would clear the question. We would be in the position of the old French company and we would be unable to know what to expect from the results of the most strenuous efforts.

But to-day we can speak differently; we can use the teachings of vast experience made on the largest scale by two successive companies, each covering nearly ten years of time. This experience leads us to the conclusion that the direct and immediate adoption of a sea-level passage to be excavated by dry methods would require an inadmissible period for execution. It leads to the principle which forms the base of my proposition—that the way to obtain the sea-level passage is not to order its immediate excavation by dry process.

THE COEFFICIENTS ADOPTED BY THE COMITÉ TECHNIQUE[a] WOULD SHOW THAT A DELAY OF THIRTY YEARS IS NECESSARY FOR THE DRY EXCAVATION OF A SEA-LEVEL CANAL.

After the fall of the old Panama Canal Company in 1888 and the subsequent formation of the New Panama Canal Company in 1894, and in view of the explosions caused by the bitter feeling existing in France, generated by the collapse of the great enterprise, the new company very wisely formed a board of the most eminent engineers of the world connected with canal construction to determine what plans should be adopted, and what results could be expected from the works.

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[a] International Board of Consulting Engineers of the New Panama Canal Company.

This Comité Technique very wisely decided to form its own judgment from facts acquired by itself, and not from the experience of the collaborators of Mr. De Lesseps.

Its work was so strictly conducted along this line that, in spite of the experience I had acquired during my long connection with the Panama work, in spite of what I had published on the subject, I was not invited, nor did I offer, to discuss with the Comité Technique the best plans to be adopted.

The experience thus acquired with entire independence by the Comité Technique led it to recommend a plan in 1898, the profile of the line of which is similar to the one I had recommended in 1892, and which was deduced, I may say, from the experience of the old French company.

In my plan of 1892 there was projected a lake formed by a dam at Bohio, the level of said lake oscillating between 16 and 19 meters above the sea level (52 ft. 6 in. and 62 ft. 4 in., respectively). The Comité Technique projected a lake at Bohio oscillating between 16 and 20 meters (52 ft. 6 in. and 65 ft. 7 in., respectively).

In my plans of 1892 I strongly urged the separation of the Chagres and the Culebra questions by having different levels for the lake at Bohio and for the waterway in the great cut, because a common level for these two parts, though attractive on account of its apparent simplicity, necessitates at Bohio a dam much too high if you wish to reduce the excavation in the great cut, or too deep a cut in the central massif if you wish to have a low and therefore perfectly safe dam at Bohio.

The Comité Technique was led by its independent studies to the same principle, and projected a flight of locks between the level of the Bohio lake and the level adopted for crossing the massif central. The only difference on this point was that the bottom level proposed by the Comité Technique across the central massif was 20.75 meters (68 ft.), while I had proposed 29.75 meters (97 ft. 10 in.) as the normal level of the bottom in that section, and even a higher level with a supplementary lock if exceptional difficulties were met in the Culebra cut.

The Comité Technique admitted such altitude because it was thought possible to reach that level during the ten years' time they fixed for the execution of the works (dam and locks) at Bohio. I proposed a higher level in the central massif; I still propose it, because I thought, and I still think, that it is possible to complete the works at Bohio much more quickly than by the plan adopted for the Bohio dam by the Comité Technique, and also because it seems to me better not to look for a too low passage now, with its risks and delays, when later prosecution of the deepening is so easy.

This shows how closely the experience gained by the old company and that gained by the new one led to identical principles as to the profile to be adopted for the canal.

The solution given to the Chagres question differed somewhat from mine, but I do not wish to debate the question now, as it has no bearing upon what I want to show—the practical identity resulting from the experiences of both companies as to what must be done to obtain with the minimum of risk the opening of traffic in the minimum of time.

Now, what has the Comité Technique considered as the probable yearly excavation in the great cut? It has based its choice of the elevation of the bottom of the summit level on the probable output of 3,000,000 cubic meters a year (4,000,000 cubic yards).

As the amount representing the local excavation in the Culebra division, according to the adopted dimensions, is 186,000,000 cubic yards for the sea-level plan, it is apparent that forty-five years would pass before the completion of the cut, if we adopt the maximum rate of excavation allowed by the Comité Technique. However, this would not be a fair comparison, as the words "Culebra division," employed in the Wallace report which necessitates the excavation of 186,000,000 cubic yards, include a greater length than the Culebra cut proper as understood by the Comité Technique, in which there is only 103,000,000 cubic yards to be excavated. Excavating at a rate of 4,000,000 cubic yards per year, twenty-six years would be required to complete the cut, not including the delays which will occur when the level of the water in the valleys is reached. Making an allowance for such delays, thirty years may be assumed to be the length of time required to complete the excavation, according to the unit estimates of the Comité Technique.

Even admitting, which I think can be safely done, that all the estimates of time of the Comité Technique might be reduced by one-third on account of the exaggerated prudence with which they were made, this would still lead to a delay of execution of twenty years for the Culebra cut. This is in accord with the opinion of the Isthmian Canal Commission, which said it would take more than twice the time of their plan, which necessitated ten years.

From this consideration we see that an immediately excavated sea-level canal would lead to the prohibitive delay of twenty years or more, if calculations of the delays of construction rest, not on unexperimented conceptions, but on the secure and broad basis of the long experiments made by the two successive French companies, with different leadership and different methods of work.

SEEMINGLY INCOMPATIBLE CONDITIONS—IMMEDIATE OPENING AND SEA-LEVEL CONSTRUCTION—HOW THEY CAN BE SATISFIED.

This logical and systematical examination of the general conditions of the problem leads us to the following consequences:

First. A sea-level canal is the logical and the necessary outcome of the Panama enterprise.

Second. It is inadmissible to entertain the idea of a direct excavation by dry methods of the sea-level canal without incurring delays which are prohibited by the imperious and immediate necessities of the world's commerce, as well as by political considerations which make it necessary to connect the oceans in the shortest time possible.

There is, however, a way which satisfies the inverse and apparently incompatible conditions, practically requiring an immediate canal connection and also a sea-level canal, within a period shorter than that necessary for the traffic to reach the maximum capacity of the canal first built. The solution lies in the disconnection of these two conditions. They would be incompatible if they had to be satisfied simultaneously, but this is not the fact.

A solution can be found if the construction of the sea-level passage is divided into two independent phases. The first phase will correspond to the opening of a permanent communication of sufficient size to provide the probable maximum requirements of the next twenty or thirty years. Such a canal must be planned under an iron rule of adopting for every section of the canal what corresponds to the maximum of facility and to the minimum of risk. The second phase will correspond to the transformation of the waterway thus created into a sea-level passage, without interfering in the least with international navigation.

Second Part.

JUSTIFICATION OF THE PROJECT—GENERAL DESCRIPTION.

As may be seen by the profile[a] annexed to the yellow pamphlet, entitled "A Solution of the Problem of Panama," the proposed waterway consists of a summit level 130 feet above the sea from kilometer 46 to kilometer 57, joined with the Atlantic sea-level section by the Bohio Lake (60 ft. to 50 ft. above the sea) from kilometer 24 to kilometer 46, and with the Pacific sea-level section by one level (60 ft. above sea level) from kilometer 57 to kilometer 59, and by another level (25 ft. above sea level) from kilometer 59 to kilometer 62.

On the Atlantic side the summit level is connected with the Bohio Lake by a flight of two locks, and the Bohio Lake with the sea-level section by another flight of two locks.

On the Pacific side the summit level is connected with the first intermediary level by a flight of two locks; the first intermediary level with the second one by one single lock; and the second intermediary level with the sea-level section by another lock.

All the locks are projected on perfect rock foundations.

Outside of the canal proper there are two important works, one at Gamboa and one at Bohio. The Gamboa dam is established near the canal across the Chagres River, at a distance of about

[a] This profile will be found at the end of the remarks, with a memorandum summing up the argument of Mr. Bunau-Varilla, dated October 30, 1905, and a second memorandum dated November 6, 1905.

one-third of a mile from the canal; this dam will be erected on rock foundations between the Cerro Obispo and the Cerro Santa Cruz, and will consist of a structure made of concrete reenforced with embedded steel, designed to hold back the waters at an altitude of 200 feet above the sea.

The Bohio dam is placed across the valley of the Chagres on the South American side of the canal. It will consist of a huge dump of clayish sand to be deposited by hydraulic methods across the valley of the Chagres to a thickness of 2,500 to 3,000 feet at the foot of the embankment, with very easy slopes on the water side of the dam, and a thickness at the top of 1,200 feet.

The spillway of the lake will be placed on the other side of the canal (thereby eliminating all possible contact of the dam with an accidental current), in one of the saddles which can be found in the chain of hills connected with the Bohio Hill, either in the saddle I indicated on my plans of 1892 or in the Rio Gigante saddle, which was selected by both the Comité Technique and by the Isthmian Commission in its report of 1901.

AUTOMATIC REGULATION OF LAKE BOHIO.

The spillway will be a weir, pure and simple, the crest of which will be at 50 feet above sea level (15.25 m.). The maximum height of the lake being at elevation 60 feet (18.3 m.), the weir will have such a length as to discharge about 140,000 cubic feet, or 5,000 cubic meters, per second, at the maximum elevation of the lake. A weir of 525 meters (1,750 ft.) in length will dispose for an indefinite period of a flood higher and of longer duration than any ever known.

These are the conditions of automatic regulation of the Bohio Lake which were adopted by the Isthmian Canal Commission in its report of 1901, and I think they cover all possible eventualities at Bohio with a marvelous simplicity. The Comité Technique adopted the objectionable feature of gates opening below the minimum level, to dispose more quickly of the water at low stage, but this is a dangerous disposition which should not be admitted.

As will be seen later on, the maximum amount of water disposed of by the weir will be normally 1,000 cubic meters (33,000 c. f.) a second, even if the greatest flood ever known, that of 1879, should be reproduced with double intensity or duration at Gamboa.

ADVANTAGES OF THE CHANNEL SELECTED FOR LEADING TO THE SEA THE CHAGRES FLOODS BELOW BOHIO.

The channel between the sea and the spillway of the Bohio Lake is, like this system of regulating the lake, an ideal element of the solution. It is the bed of the River Chagres itself, which will constitute the derivation for nearly its entirety. Two artificial beds only have to be dug, one between kilometers 16 and 22 and another between kilometers 8 and 10. The latter is open already and needs only widening.

The extreme simplicity which results from the selection of this side of the canal is obvious. The bed of the river is wide and deep, and by natural accretion it has spontaneously deposited earth on its banks which forms, as it were, two natural embankments, preventing the overflow. It must be remarked, also, that according to what I established in my book of 1892 (p. 156), the reduction in the length of the river between Bohio and the sea, due to the short cut opened between kilometers 16 and 22, will allow the Chagres to dispose of a flood of 1,000 cubic meters as it disposes to-day of a flood of 850 cubic meters, which is a very small, ordinary wet-season freshet, without any overflow out of the bed of the river.

I proposed this solution, which is one of the great advantages of the Bohio Lake, in my plans of 1892. For a reason which I ignore, it was not adopted by the Comité Technique in 1898, which provided for two deviations below Bohio, one on each side of the canal; but it has been taken up again since by the Isthmian Canal Commission in its report of 1901 and forms a characteristic feature of the project they adopted.

After this summary but precise description of the different works to be executed, let us examine the way the present project meets the two great technical problems of the Panama Canal—the Chagres question and the Culebra question.

THE CHAGRES PROBLEM.

I propose to resolve the question of the control of the Chagres by the erection of a dam at Gamboa, holding back the water of the Chagres at an elevation of 200 feet.

The Gamboa dam, after having formed an essential part of the old Panama company's plans, was abandoned by the new company. I consider it of exceptional importance that recently the Engineering Committee of the Isthmian Canal Commission reported again in favor of this location for a controlling dam. This opinion confirms my own judgment, which has always been that this location is the most perfect one to select.

Though the old company's plans projected a dam of earth, I ordered, in 1885, borings to be made in view of the erection of a masonry dam, which I considered, and still consider, the only form admissible. They gave satisfactory results for the foundations of a masonry dam.

As the Alhajuela location was selected by the Comité Technique in preference to Gamboa for purely constructive reasons, it is justifiable, I think, to draw a comparison between the two dams. This will allow us to review the principal elements of the Chagres flood question, and follow the system of the Comité Technique, which forms the foundation of the whole logical argument.

THE GAMBOA DAM COMPARED WITH THE ALHAJUELA DAM—ITS SUPERIORITY.

From every point of view, except that of mere construction, the Gamboa location is infinitely preferable to the Alhajuela location. The restricted dimensions of the Alhajuela Lake necessitate an incomplete solution of the Chagres floods question, while those of the Gamboa Lake allow an entirely perfect solution and at the same time a perfect solution of the question of water storage for the dry season.

The Gamboa Lake at the level of 200 feet will have a surface of 43.3 square miles (11,209 ha.) and a surface of 30.8 square miles (7,963 ha.) at elevation 170, say an average surface of 37 square miles (9,500 ha.), owing to surface oscillation.

The Alhajuela Lake, as it was projected by the Comité Technique, had an elevation of 213 feet, a surface of 3,000 hectares (11.5 sq. mi.) and an average of 2,600 hectares, due to surface oscillation.

The much larger surface of the Gamboa Lake—just about four times that of the Alhajuela Lake—provides a much better control of the Chagres floods.

The Comité Technique based its system of control on the highest flood recorded in the last fifty years, the celebrated flood of 1879, which was not actually measured, and the height of which is based more on remembrances than on real technical data. It was, however, a very wise thing to take it as a base of calculation, because it may be considered as a maximum. The average flow of the river was about 1,600 cubic meters (53,000 c. f.) per second at Gamboa and about 2,600 cubic meters (86,000 c. f.) at Bohio for forty-eight hours, according to the Comité Technique (pp. 28–31, report of November 16, 1898).

The Comité Technique considered that the following should be the method of controlling such a flood. It is expressed here in round figures:

The Alhajuela Lake should store 600 cubic meters (20,000 c. f.) per second, and allow 1,000 cubic meters (33,000 c. f.) to pass into the lower river bed, thus reducing the flow of the river at Bohio to 2,000 cubic meters. The resulting storage in Alhajuela Lake would amount approximately for the period named to 100,000,000 cubic meters, or about 3,300,000,000 cubic feet.

The Bohio Lake would have to store 800 cubic meters a second (27,000 c. f.) and allow to pass 1,200 cubic meters (40,000 c. f.) by the lower river bed or by the deviation, namely, 700

cubic meters on the North American and 500 on the South American side of the canal, which would amount to a storage of about 140,000,000 cubic meters, or 4,600,000,000 cubic feet.

The storage of 100,000,000 cubic meters (3,300,000,000 c. f.) in the Alhajuela Lake corresponds to a variation of level of about 4 meters (13 ft. 2 in.). The same amount of water stored in the Gamboa Lake would amount to a variation of level of 1.05 meters (3 ft. 5 in.).

Such an increased power of control is essential and there is every reason to retain a larger amount of water above a dam such as at Gamboa, for the following very important reasons:

If the amount of water that is allowed to pass from the upper lake does not reach 500 meters (17,000 c. f.), instead of 1,000 cubic meters (33,000 c. f.), it can, without any inconvenience, pass through the canal, whether the canal is a sea level one or not. The cross section of the canal is about 600 square meters and will be increased later. To allow this mass of water to flow into the canal would produce a current less than 2 knots per hour, a current which has the velocity of the tidal currents between the Bitter Lakes and the Red Sea on the Suez Canal, and which has never caused any inconvenience to traffic.

It may be further stated that such currents will only take place in case of great floods, which occur every three or four years on an average and last only two or three days, and that the ordinary usual discharge for ordinary cases will be 330 meters (10,000 c. f.), giving a 1-knot current.

NO CHAGRES SEDIMENTS TO BE FEARED WITH THE GAMBOA LAKE.

It may be also convenient to remark that the waters dropped from the lake will have no sediments. The Chagres is not a heavy sediment-carrying river now, as the general formation of the country consists of hard material covered by the intense tropical growth. Outside of that the formation of the Gamboa Lake will overflow all the low part of the Chagres Valley and of its tributaries, and will meet the rivers near their heads, not allowing any current in the part of their bed where the friction of water on the bottom disintegrates its elements and produces the light material transported by the floods and called sediments.

If we admit this new limit of flow of 500 cubic meters instead of 1,000 cubic meters into the river below the Gamboa dam, we see that for a flood identical to the maximum one the storage in the lake above would have to be 1,100 cubic meters instead of 600 cubic meters per second, which would place 190,000,000 cubic meters (6,300,000,000 c. f.) in forty-eight hours behind the Gamboa dam. This would correspond to a variation of the lake level of about 2 meters (6 ft. 6 in.).

On the other hand, the flow at Bohio, which naturally would be, as we have seen, 2,600 cubic meters (87,000 c. f.), would be reduced to 1,500 cubic meters (50,000 c. f.) per second if 1,100 cubic meters (37,000 c. f.) are withheld at Gamboa. If we store in Lake Bohio 800 cubic meters per second, as the Comité Technique proposed, the flow from this lake will be reduced to 700 cubic meters per second, or, to the amount of water which the Comité Technique proposed to send into the North American side of the canal only; that is, in the channel where the Chagres bed is, for the larger part, and this would allow dispensing entirely with the deviation on the other side without changing the proposed flow in the North American one.

THE EFFICIENCY OF GAMBOA LAKE FOR CONTROL OF FLOODS VASTLY SUPERIOR TO THAT OF ALHAJUELA LAKE.

This clearly shows how vastly superior in efficiency is the Gamboa dam to the Alhajuela dam as regards its essential purpose, that of controlling the Chagres floods.

With a variation of level of about 6 feet 6 inches in the Gamboa Lake instead of 13 feet 2 inches in the Alhajuela Lake, an infinitely superior system of control is attainable, which avoids the costly and dangerous work of a deviation alongside the canal between Gamboa and Bohio, or by tunnels through divides, while at the same time it allows the employment of only one side, the good side, of the canal between Bohio and the sea for the carrying away of the floods.

It is obvious that the storage can be brought much farther, and we shall see later how I propose to take advantage of the precious storing power of the lake to solve the flood and the dry season storage questions.

OTHER ADVANTAGES RESULTING FROM THE POSITION OF THE GAMBOA DAM—IT GIVES NO VITAL PART TO THE BOHIO LAKE FOR THE CONTROL OF THE CHAGRES FLOODS.

The advantage resulting from a much larger lake area is not the only one in favor of the Gamboa location. Its immediate proximity to the canal allows me to state, as we have seen, that the waters sent into the canal will not carry with them any sediment at all. The Gamboa dam regulates infinitely better than the Alhajuela Lake the Chagres floods, and at the same time it will clean entirely the waters emitted, which would not be the case with the Alhajuela location. The waters emitted would be pure also at the outlet of the Alhajuela Lake, but having to receive many tributaries between the dam and the canal they will bring into it sediments.

Another exceptional advantage of the Gamboa location is the proximity of its waters to the summit level, if one is decided on in the central massif according to my proposition of 1892, that of the Comité Technique, and the one I am now presenting to you.

The connection between the summit level and the lake is immediate with the Gamboa Lake; it is long and difficult with the Alhajuela location. It necessitates for the last location a canal about 10 miles long (15.5 km.), of the most objectionable character, if one thinks of the enormous importance of such a connection and of the terrible consequences of its destruction at a single point during the canal operation.

On the other hand, with the Gamboa location of the dam it is possible to obtain a complete solution of the Chagres floods problem without giving any part to play to the Bohio Lake except a subsidiary one. The Bohio Lake can, therefore, gradually disappear during the works of transformation without troubling the regular system of the control of Chagres floods.

I consider that the proposition made by the Engineering Committee, composed of General Davis, Professor Burr, and Mr. Wm. Barclay Parsons, to erect a dam at Gamboa is one of the most important recent contributions to the Panama question.

I do not agree, however, with the method of construction they proposed, and I shall reserve this question for discussion later on. I wish now to dispose of the storage question entirely.

PROPOSED SYSTEM FOR THE CONTROL OF FLOODS AND THE STORAGE FOR DRY SEASONS.

As we have seen, the Comité Technique based its system on the simultaneous storing power of the Bohio and Alhajuela lakes, and we have seen, while examining the system of the Comité Technique, how improved the same system would be with the Gamboa Lake. In view of the storage power of the Gamboa Lake I do not think it necessary to employ the Bohio Lake for the control of the maximum flood known. It should be reserved to control a still greater or a still longer flood. It should be, in a word, the emergency flood controller.

For this reason I have supposed that it would not have to deal with the maximum flood known, and that with such a flood it would have, in the highest period, to handle only what comes into the lake outside of the Gamboa outflow; that is to say, 1,000 cubic meters (33,000 c. f.) per second out of 2,600 cubic meters (86,000 c. f.), which is the greatest known flow at Bohio admitted by the Comité Technique.

To pass such a mass of water over its weir, 525 meters in length, the Bohio Lake will have to rise 1.04 meters (3 ft. 5 in.) above the minimum level of 50 feet. This will mean the storing of about 50,000,000 cubic meters or 1,700,000,000 cubic feet.

The space between elevation 53 feet 5 inches and elevation 60 feet will not be used except in the case of emergency; that is, a flood of hitherto unknown intensity or duration. At elevation 60 the weir will discharge 140,000 cubic feet (5,000 c. m.) per second indefinitely.

As we require of the Bohio Lake, in case of great floods, only the handling of what falls from the basin below Gamboa, we must store in the Gamboa Lake the maximum flood known there, 1,600 cubic meters per second during forty-eight hours; this means a storage of 276,000,000 cubic meters or 9,200,000,000 cubic feet, which will correspond to a rise of the level of 2.9 meters or 9 feet 8 inches. So far as is known this is the largest amount of water discharged at one time.

In order to foresee even the improbable, we shall reserve for the storage of floods a space equal to twice that; that is to say, a variation of level of 20 feet.

This will store the maximum flood known during ninety-six hours; or during forty-eight hours a flood of 3,200 cubic meters (106,000 c. f.) a second—twice as great as the largest known.

THE BOHIO LAKE AN EMERGENCY FLOOD CONTROLLER, WHICH MAY GRADUALLY DISAPPEAR.

We are thus protected by the largest margins of safety ever contemplated. If, however, nature sends a still harder trial, it will be only necessary to let the water drop into the canal as it comes. This will cause no danger, as the Bohio Lake is there created to act as an emergency controller for a 5,000 cubic meter (140,000 c. f.) flood of indefinite duration.

In the first period of the life of the canal Lake Bohio will exist, and it will be very easy and cheap to enlarge the narrow parts of the canal in the upper section of Lake Bohio in order to admit even 1,600 cubic meters or more into the canal without creating a current damaging to navigation.

In the second period of the canal life, the sea-level period, its dimensions will be necessarily enlarged and the cross section brought to about 1,000 square meters or more. With such a section a flow of 1,600 cubic meters a second will generate a current of only about 3 knots.

Such an accident as the one we suppose would certainly not happen once in a century, as the flood on which we have based our calculations happened but once in fifty years, and as we are normally prepared to dispose of a still larger flood of double duration and equal violence, or of equal duration and double violence, without dropping any water from the Gamboa Lake.

The fact of not making the Bohio Lake a vital organ of the Chagres regulation, as the Comité Technique was forced to do, owing to the adoption of the Alhajuela location, entirely liberates the transformation of the canal from the Chagres flood question. During the transformation the Bohio Lake will disappear without impairing the regulation of the Chagres, which could not have been done with the system adopted by the Comité Technique.

STORAGE FOR DRY SEASON—IT WILL BE AMPLE FOR 50,000,000 TONS OF TRAFFIC.

The part which the Gamboa Lake has to play is double. First, it must form a water reserve for the dry season, and, second, it must control the floods at the same time. The months of November and December are precisely the months when, if you expect a flood, you must have your reservoir low, and if you expect an early dry season you must have its surface high. Therefore there are two distinct volumes affected, each one to its individual service.

The volume of the lake between level 160 and 180 will be devoted to storage for the dry season, and the volume of the lake between 180 and 200 will be devoted to the storage of the floods, as we have seen. There will thus be no conflict between two inverse necessities, nor any discretion left to weather prophecy.

The volume stored for the dry season will amount to about 550,000,000 cubic meters or 18,500,000,000 cubic feet. This will mean for every one of the one hundred days of dry season 5,500,000 cubic meters, or about 67 cubic meters a second, which, increased by the minimum inflow of 14 cubic meters, would give about 80 cubic meters a second for the canal, or 2,700 cubic feet.

The Isthmian Canal Commission, in its report of November 16, 1901, declared that for 10,000,000 tons the canal will absorb for the lockages 406 cubic feet per second (13.5 c. m.), and for various needs not varying with traffic another quantity of 664 cubic feet per second, making 1,070 cubic feet per second (35.6 c. m.) in all.

It results from these figures that the amount of water stored behind the Gamboa dam will satisfy a traffic of 40,000,000 tons with the height of the locks of the Canal Commission, and therefore a traffic of 50,000,000 tons with the locks of less height, which I propose to use.

One sees that the Gamboa Lake affords an equally perfect solution of the storage question as it does of the flood question. The traffic it guarantees during the dry season is precisely the traffic which is considered the highest traffic attainable with a lock canal.

When the second phase of the canal life will be reached, when the sea-level canal will be constructed, the dry-season storage will have ceased to be necessary and the flood-controlling power of the lake will be double; in other words, the lake will be able to absorb between level 160 and level 200 four times the mass of water the largest flood known in fifty years has brought.

The rules attending the operation of the Gamboa Lake will be precise and simple. It will always be kept in the wet season at level 180, so that it may be constantly ready to take care of the largest flood without sending down into the Bohio Lake any water as soon as the latter lake has risen 1.04 meters (3 ft. 5 in.) above its minimum level of 50 feet. In the dry season it will provide for the needs of the summit level, and with the maximum probable lock-canal traffic will not go below the 160-foot watermark.

CONSTRUCTION OF DAM AT GAMBOA IMPOSSIBLE WITH THE SPOILS OF THE GREAT CUT—MUST BE A CONCRETE DAM.

Rock foundations are found for the dam between Cerro Obispo and Cerro Santa Cruz approximately at the level of the sea. The height of the dam above its foundations will therefore be 200 feet in round figures.

There is nothing exceptional in such a height. Many structures of this size have been erected of masonry. Some, the Croton dam, for example, are of still greater height. I think that the vertical distance between the water level and the deepest foundation level is approximately 300 feet at the Croton dam.

Such a dam can be closely calculated according to methods which have the sanction of a long experience. The additional element of certainty that the embedding of steel can give to a cement concrete dam still increases the desirability of such a structure, and wipes out all suspicions which might arise from the possibility of an earthquake.

I have already stated that I considered the selection of the Gamboa location by the Engineering Committee of the Isthmian Canal Commission for a dam controlling the Chagres floods as one of the most decisive and happy contributions to the solution of the Panama problem; but my opinion differs from that expressed by the committee on the question of construction.

It has been proposed by that Engineering Committee to raise an earth dam with the spoils of the great cut with a core wall inside. An earth dam with or without a core wall is an earth dam; the core wall is but an additional element of safety. The stability and the resistance of the dam must be determined by the character of the dam itself; it must be judged on its own merits without a core wall, if we want to have a fair and scientific conception of such a structure.

Let us therefore reason without taking into consideration the supplementary element of stability, the core wall, and let us put squarely the question:

Is an earth dam 200 feet high, made with the spoils of the great cut, possible at Gamboa? I answer emphatically no; and I answer after years of study on the spot, because it was also the plan of the old Panama Canal Company to erect there a high earth dam with the spoils of the great cut, and because I sincerely hoped when I arrived on the Isthmus in 1884 that I could reach the technical certitude that it was practical and feasible.

I do not think it is practical or feasible for three different reasons, each of which would be enough to condemn the idea:

First. Such a dam will be erected there for all future time; it will be the key of the whole canal whatever be the first form adopted, whatever be its ulterior transformation later. It, therefore, must be built in order to give forever a substantial and absolute guaranty of stability.

Now, earth dams are always considered as unsafe structures where they reach an important height. Even made of the best materials possible, even built according to a method that does not leave any doubt about the homogeneous and complete perfection of all its elements, even with the possibility of giving it a thickness ten times larger than what is strictly necessary, I do not think it advisable to build the Bohio earth dam with a head of water of more than 60 feet.

Within those limits and with such precautions an earth dam is completely safe and a satisfactory solution, but to consider an earth dam having a water head three times greater is something which I can not contemplate for a definite and perpetual structure. I concur with the first Isthmian Canal Commission in thinking that at Bohio even an altitude of 92 feet could not be admitted without the supplementary security of a core wall; but I would not go any further even with the best core wall.

I may be considered as overtimorous, but in technical art, when no calculations are able to satisfy me, I do not consider such lack of boldness as a fault.

Second. Its erection across the bed of a violent, unruly stream, without having, as we have at Bohio, a bed of the same level and of the same cross section through which it may be deflected, seems to me will be attended by innumerable difficulties and condemned to certain failure. The absence of a wide and deep bed into which the river may be deflected while the depositing of the earth of the dam is going on in the dried site of the dam, is a great objection to the construction of a dam anywhere but at Bohio. It applies to Gamboa; but it applies also to Gatun, where an earth dam has been sometimes proposed without paying sufficient attention to the conditions of the site.

Third. The great apparent advantage of an earth dam is the possible employment of the vast mass of material to be excavated from the central massif, but this advantage vanishes like the mist in the sun when you come to consider the nature of the material to be extracted.

There is not, among all kinds of earths, one which is more unqualified for such a purpose. The earth employed in a dam must be of such nature that all its particles come into close contact with one another, leaving no room between them for the water to pass. This contact can be obtained with a suitable soil either by mechanical compression, or, much better, by a good method of handling the suitable ground. Neither by compression nor by any other system will any adherence ever be obtained for the particles of the spoils of the great cut.

CHARACTERISTIC FEATURES OF THE INTERNAL ELEMENTS OF THE CULEBRA CUT—MANY ERRORS COMMITTED ABOUT THIS SUBSTANCE.

It consists of rock in limited proportion, of hard rocky clay, of argillite for the greater part, and of some softer clay near the surface of the ground.

There have been many opinions expressed about this argillite, this rocky clay, of the great cut. Many errors have been committed about its stability. In fact, it is a hybrid material, and some see it as a rock, others as clay. In reality it is a soft rock which, while in place, with the necessary amount of internal moisture, is, under or above the water, perfectly hard. Under water, it is absolutely stable; above water it may weather somewhat, but in insignificant proportions so long, I repeat, as it is not taken away from its natural position. But if we take a piece of this clayish rock and expose it to the atmosphere it loses its water, the molecules separate from one another, and it falls into separate particles, as lime does when it comes in contact with the humidity of the air. If you put a desiccated piece of this clayish rock in water it falls into pieces.

Many very distinguished minds have been curiously misled about it, over and over again. I have heard that rocky clay called soluble clay several times. Some have entertained the most unfounded fears about the action the water would have on the sides of a cut opened through this substance.

NO WALLS AT CULEBRA ARE NECESSARY.

Even the Comité Technique was a victim of that error, and projected walls in the Culebra section to protect this so-called soluble clay from the contact of a supposed solvent.

In reality, these walls never have to perform such part; and, by the way, it is well to say that if the eminent engineers of the Isthmian Canal Commission retained these walls in their project, it was not in the minds of several of them to protect the clay against the water, but to protect the ships against accidental contact with some protuberance. Mr. Noble and Mr. Morison stated that fact to me, and in the writings of General Hains the same opinion may be inferred.

It may be worthy of note that the same error was committed during the construction of the Suez Canal; great engineers, like Hawkshaw, predicted the most awful consequences if the clay of the canal prism were not protected from the contact of the water between the Bitter Lakes and the Red Sea. The necessary time to make the protecting masonry not being available, nothing was made, and nobody has since remarked the absence of this supposed indispensable protection.

This rocky clay, which is extremely easy to blast and to load with excavators or steam shovels after a very light blasting, retains its moisture when dumped and disintegrates but partially. Its surface only becomes soapy, and there is practically no friction between a piece of the clay and its neighbors. In one word, it forms an embankment of pieces of rock, the surface of which is transformed into soap.

INSTABILITY OF THE SPOILS EMBANKMENTS DURING THE RAINY SEASON PARALYZED FOR YEARS THE EXECUTION OF THE WORK.

It has, therefore, no power of retaining water, but an extreme tendency to slide. This has been one of the greatest difficulties of the excavation of the Culebra cut, and the slides of the embankment as soon as the wet season set in were for several years the practical cause of the paralysis of the work in the great cut. I overcame that difficulty only by protecting as much as possible the spoil embankments from receiving the water from the hills above.

A TENTATIVE DAM OF 8 TO 10 FEET HEAD WITH THE SPOILS OF CULEBRA A FAILURE.

I can say that this notion of the character of the Culebra clay, as regards employment in dams, is not purely theoretical. In spite of my knowledge of these facts I tried an experiment in this very matter. For the feeding of a dredge pool on the Atlantic side of Culebra it became necessary to raise the level of the upper Obispo River about 8 or 10 feet. I had for this insignificant work in enormous superabundance all the material needed, and thought after all that for such a very small head I might as well try to dam the creek with that material. Throwing across the little valley an embankment 18 feet high, I unloaded train after train; the water always went through and never was raised above 1 or 2 feet. I had to use a centrifugal pump to raise the necessary quantity of water for feeding the pool.

Excuse me, gentlemen, for having insisted so long on this point, but I am sure you will be met by different theories of the Culebra clay. The knowledge of this clay has a bearing of capital importance for certain most important items, such as the Gamboa dam, the Culebra walls, etc., and I thought it necessary to make a full explanation.

PROOFS OF THE STABILITY OF THE CULEBRA ARGILLITE WHEN IN ITS ORIGINAL PLACE AND UNDER WATER.

You will remark how unfounded are the terrors of this rocky clay dissolving in the water of the canal when you observe that the ground of a place called Las Cascadas, where the Obispo River had a waterfall, is constituted of this very same material. If it were destructible by water, that waterfall would never have existed.

This has also been seen in wells driven through the Culebra cut, long since abandoned and filled with water; after years of neglect their sides were just as well defined and hard as the day after the opening of the well.

An earth dam at Gamboa is impossible, therefore, because it would not be sufficiently secure if perfectly built, because it could not be built in contact with the river, and because the material to be employed is not the right kind to make a water-tight dam with.

Therefore, a well designed dam made of concrete with embedded steel is necessary. The coefficient of security must be very large. The dam must resist even an increased water pressure due to an increased density of the water on account of the earth in suspension, which would occur if spoils are dumped near the dam.

Its construction will be very simple and the Chagres will not be able to harm it. Large openings will be left through the dam to allow the river to pass during the construction, which will be closed in proper time by steel gates and after that filled with concrete.

I have finished with the Gamboa dam. Let us now turn to the Bohio dam in order to explain the system I advocate for its construction.

CONSTRUCTION OF THE DAM AT BOHIO.

The Bohio dam which I proposed in 1892 to build in order to obtain a completely satisfactory solution of the Chagres question was to form a lake oscillating between 16 and 19 meters (respectively 52 ft. 6 in. and 62 ft. 4 in.). In 1898 the Comité Technique proposed an earth dam at the same site for a lake oscillating between 16 and 20 meters (respectively 52 ft. 6 in. and 65 ft. 7 in.). The Isthmian Canal Commission, in their report of November, 1901, also recommended an earth dam at Bohio, with a core wall built from the rock foundations, for a lake oscillating between 85 feet and 92 feet (respectively 25.92 and 28.06 m.).

I propose to-day a lake oscillating between 50 feet and 60 feet elevation; the slight variation of altitude from my original proposal corresponds simply to the convenience of expressing the elevation in round numbers in English measurements. It involves no matter of principle.

The construction of a core wall (in the Isthmian Canal Commission plan) was the object of much discussion when the foundations were thought to be found at the elevation —128 feet (—42 m.); but the difficulty has been greatly increased on account of the obligation of going deeper still to obtain the satisfactory foundation, to a depth of about 163 feet below sea level (53.4 m.). Of course, it is idle to say that is beyond the engineering possibilities of our days, but it is equally idle to sustain that it is an easy work to dispose of.

NO EARTH DAM ON THE ISTHMUS SHOULD REACH 92 FEET WITHOUT A CORE WALL.

There are very few engineers, however, who would take the heavy responsibility of constructing an earth dam at Bohio at elevation 92 feet (28.06 m.) without the supplementary guaranty of a core wall. These conditions seem to have disposed of building a dam at such an altitude, and to have turned the minds of competent engineers to a low dam for a maximum water elevation of 60 feet (18.16 m.).

A low dam of that order becomes a very simple and easy construction if the method is properly chosen. The dam conceived by the Comité Technique was what might be called an academical dam—a dam which undoubtedly would very well correspond to conditions of the old civilized countries, where intelligent labor is abundant and where material and ground are scarce. It corresponds to European conditions, not to those of the Isthmus. It consists essentially of a large embankment made of a mixture of sand and clay carefully mixed together (corroi), deposited in small quantities at a time, beaten with a wooden rammer so as to incorporate it closely with the corroi already laid in place. The embankment is 15 meters (49 ft. 3 in.) thick at the summit and 120 meters (393 ft.) thick at the foot. I consider as very questionable whether any work of that kind would have been a success on the Isthmus.

NEITHER CORROI NOR MASONRY ARE ADMISSIBLE ON THE ISTHMUS, OWING TO LACK OF SKILLED AND RELIABLE LABOR.

In spite of the considerable period of time which the Comité Technique thought it would take to erect it, I am persuaded that such a conception of the Bohio dam would have ended in disaster. The exceedingly unreliable quality of labor and the relaxed vigilance of the overseers are, we know, the principal factors which regulate the works. For the very same reason that masonry on a large scale is impossible on the Isthmus and must be replaced by mechanical masonry, by concrete, an embankment of corroi is impossible to erect with the necessary perfection.

EARTH DAM AT BOHIO TO CONSIST OF A MOUNTAIN OF CLAYISH SAND TRANSPORTED AND DEPOSITED BY WATER.

The solidity of the structure must rest on the system of construction, not on the good will and vigilance of the laborer, and it must be conceived in such a way that nearly unreasonable margins of safety provide against all imaginable risk. This is the base of the project of the Bohio dam which I have had the honor of submitting to the President of the United States.

Let us first see the dimensions. If we give 2,500 to 3,000 feet thickness to the embankment at the foot—that is to say, about six or seven times the thickness of the Comité Technique's embankment—and 1,200 feet thickness at the crest—that is to say, about twenty-five times the corresponding dimensions of the Comité Technique's project—we shall have fulfilled the conditions as to the necessary margin of safety.

But it is also necessary that, in addition to such margin, the quality of the structure should be as high graded as that of the most perfect corroi the Comité Technique could hope to obtain and which it would never have obtained.

Let us first consider the quality of the natural ground in the valley above Bohio. It consists of an indefinite quantity of sandy clay easy to dredge, easy to put in suspension in water, easy to manipulate with centrifugal pumps. Thanks to these exceptional qualities it will be easy by purely mechanical manipulation to send the material in a state of extreme division in suspension in water to the location of the dam. The water will drop the material thus transported in a state of ideal adherence and cohesion necessary for a perfect dam. The system I propose guarantees entirely for the embankment a quality never obtainable by the hand methods of the corroi construction. Aside from the advantage of giving an exceptional perfection to the huge mass of impervious material which will be thrown across the Chagres Valley this method has also that of simplicity and rapidity.

In my letter to the President of the United States I explained how two powerful dredges, excavating and working in combination with a corresponding number of centrifugal pumps which elevate, by the Dutch method, the water-bearing material to the necessary height for transporting purposes, would make certain the execution of this huge deposit within one year. This method leaves nothing to desire from a practical standpoint.

Now, gentlemen, will you allow me to answer an observation which is inserted in the pamphlet bound in gray which was prepared for your studies and which bears the title "The Panama Canal, Part IV, projects of M. Bunau-Varilla and of," etc. In the remarks that precede my letter to the President it is said that the estimate of four years' time for the conclusion of the Bohio works is "oversanguine." This appreciation is based upon the fact that the Comité Technique estimated at ten years the time necessary to execute the works at Bohio.

This last statement is perfectly true, but I do not think it absolutely just to dispose of my estimate of the required time on account of the estimate of time made by the Comité Technique for their own project. It is not just, first, because the estimates of time do not apply to the same method of construction and therefore are not comparable, and on the other hand, because the estimates of time of the Comité Technique have always, and justly, been considered as overcautious.

It is highly probable that the method of constructing the Bohio dam as I propose it would have justified the Comité Technique in reducing by three or four years, at least, its estimate of the time necessary, and that therefore they would have admitted six or seven years as sufficient for the execution of the Bohio works.

ESTIMATES OF TIME OF THE COMITÉ TECHNIQUE CAN BE REDUCED IN THE PROPORTION OF 4 TO 5.375, ACCORDING TO THE ISTHMIAN CANAL COMMISSION.

On the other hand, I said at the beginning that the estimate of time of the Comité Technique could very conservatively be reduced by one-third. It is interesting to note that this has been also more or less the opinion of the Isthmian Canal Commission, as can be inferred from their

report of November, 1901. In that report we see that the 43,000,000 cubic yards to be excavated in the Culebra section could be disposed of in eight years after two years of preparation. From this statement it results that the estimate of yearly practical production by the Commission is 5,375,000 cubic yards. If we compare it to the 4,000,000 cubic yards admitted by the Comité Technique as the basic annual production we see that the Isthmian Commission's view of the time required for the same object is to the Comité Technique in the proportion of 4: 5.37.

MY ESTIMATION OF THE TIME NECESSARY FOR THE BOHIO WORKS NOT CONTRADICTED BY THE COMITÉ TECHNIQUE'S FIGURES.

If we apply this ratio to the seven or six years above named as sufficient, we find five years and one-third, or four years and one-half as the time applying to the works I project at Bohio, if viewed from the Comité Technique's standpoint, but with the correction resulting from the Isthmian Canal Commission's judgment. Now to say four years or to say five years is to say practically the same thing for an estimate of the future construction of such a difficult enterprise.

I consider, therefore, that I am not at all condemned by the Comité Technique's valuations of the time necessary for their work at Bohio, and that, on the contrary, there is harmony between their figures and mine.

Another practical demonstration can also be found in the same report of November, 1901, of the fact that the Isthmian Canal Commission considered that the estimates of time of the Comité Technique could safely be reduced. The works projected at Bohio by the Isthmian Canal Commission were singularly more important and more difficult than those of the Comité Technique. The American Commission had to erect a dam 92 feet high, instead of a dam of 65 feet 7 inches. They projected a weir 2,000 feet long, when the Comité Technique's project was only about 200 feet long, with movable gates. They had to build a core wall across the valley of the Chagres, having about 220 feet height above foundations supposed to be 128 feet below sea level.

In spite of the increased mass of work the American Commission did not increase the time set for the comparatively easier project made by the Comité Technique. The Commission adopted the same number of years, but they declared that the controlling feature was the Culebra cut and not the other works, and that the last named could be finished within the period necessary to excavate the Culebra cut.

It is obvious from this remark that the Commission thought the Comité Technique had been overprudent in estimating the time, both for the excavation and the accessory works. For these reasons it is therefore logical to reduce, as I did, the time the Comité Technique allowed, and this must be done, as I have said, both on account of the simplification of the works and of this overestimation of time.

ALL THE WORKS AT BOHIO CAN BE MADE IN FOUR YEARS.

But I do not want to justify my valuation of the time necessary for the works at Bohio by basing this valuation on a comparison with an altogether different conception, even modified according to reasonable considerations. You will judge whether I am right or wrong on the intrinsic merit of my own justification. This is how I conceive the proper method of procedure:

A year and a half should be devoted to the construction of the dredges, tugs, and scows that will excavate and transport to the dam the material, to the erection of the centrifugal pumps that will throw a large quantity of water into the scows in order to put the dredged material in suspension at the origin of the dump, and of the centrifugal pumps that will suck this sort of soup and elevate it to a sufficient altitude to conduct it in closed pipes to the point of discharge.

You know that there is no practical limit to the height nor to the distance, if we use centrifugal pumps sucking the material from one another, or placed at different points of the pipe in order to introduce at the proper place the amount of mechanical energy required.

It is not out of place to suggest here for the rapid installation of the dredges and scows that the hulls should be shipped in sections as large as possible in order to avoid labor on the Isthmus.

The volume of the sections should be limited only by what the Panama Railroad can transport, viz, 30 feet by 9 feet by 13 feet.

Such a vast amount of machinery can be easily driven electrically by one single electric central station, furnishing the dredges and the centrifugal pumps with the necessary power. The one year and a half limit can be easily made sufficient by giving the orders in or outside of the United States to makers familiar with such plants, which are of common use in Holland, and by paying the necessary premiums for rapid delivery and fixing very high penalties for nondelivery in contract time. During this year and a half the excavation of the Bohio Hill, already lowered down to 40 feet above sea level, can be finished and the foundations of the locks made. During the same time the spillway, which will consist of excavating a low saddle, must be also attacked with energy. After a year and a half the river bed will be closed by a temporary deviating dam of the kind so often used in the United States and in Canada, consisting of wood rafts formed by cross beams bolted together, which can be floated into their places and sunk by filling with stones the empty spaces between the beams. This kind of structure is handy and quick and forms a strong obstacle to the river, an obstacle which is quickly reenforced and made practically water-tight by dumping sand ahead and stones behind. This temporary deviating dam will be, after completion of the reenforcement, raised to 50 feet above sea level. At this height the river can not overflow it, and even with a large flood all will pass in the new channel through the space opened for the locks.

After another year the embankment of the dam must be practically completed and work on the spillway conducted so as to give way to the highest flood over the weir, and two years and a half, which corresponds to these two periods of time, ought to be ample for that special work.

At the end of two years and a half the valley will be closed by the appropriate steel gates placed across the lock excavations, water allowed to rise, and the completion of locks prosecuted. This prosecution will practically consist in handling a large mass of sand, cement, and steel. Everything depends on the storage next to the place of employment of the necessary amount of material. As two and a half years will have been left to store the necessary material, it appears that the hardest part of the whole work will already be done and that in one year and a half, with the proper machinery, the whole system may be easily finished, making four years in all for the whole work at Bohio.

I am convinced that, with the sincere and earnest intention to accomplish it, this programme may be exactly carried out.

NO FEAR FROM THE PERVIOUS SUBGROUND BELOW THE BOHIO DAM.

I may be allowed to add that this rapidity of construction will not be bought at the expense of solidity of construction. There seems to be no question about it, for the mass constituting the dam itself. Can any question be raised about the ground under the dam proper? Is there any danger to result from passage of water under the impervious dam through the partly pervious subground?

It has been shown by the great and lamented engineer, George Morison, that according to certain coefficients of filtration recently contributed to science by an eminent engineer, Mr. Stearns, member of this Board, that even with a head of 92 feet the filtration could not, under the most unfavorable circumstances, become larger than 40 cubic feet (1.3 c. m.) per second, which is insignificant. This figure is calculated upon the hypothesis that the pervious ground underneath the dam would communicate with water immediately above and below the dam.

But this can not be the case. When this pervious ground was deposited by the river, the headwaters of the Chagres was at a shorter distance from Bohio than it is now, and the waters had not had time to reduce the sand into silt. The distance of Bohio from the head of the river was then the same as is Gamboa now. But since, as the head withdrew toward the interior, more recent and more completely disintegrated sediment covered the ancient ones and formed over them an impervious blanket between Bohio and Gamboa. It may be safely assumed that the pervious underground does not communicate with the water nearer than 10 miles above Bohio

and nowhere below. Even assuming the pressure would determine a communication near the dam below, the blanket above would prevent filtration to reach more than 4 or 5 cubic feet a second.

The Bohio dam will, therefore, if so conceived, be a perfect structure from whatever point you examine it.

SYSTEMS PROPOSED IN THE PAST FOR THE CONTROL OF THE CHAGRES FLOODS.

After having presented what may be considered as a complete solution of the Chagres flood question; after having not only justified the dispositions recommended but also explained the system of construction of its vital elements; after having shown that this system enjoys the precious quality of adapting itself to all the forms the canal will have between the high-lock form and the sea-level form during the transformation, it is not useless to show how the same question has been treated in the various projects submitted heretofore. We have thrown sufficient light on the solution presented by the Comité Technique of the New Panama Canal Company in 1898; it is therefore completely explained. Let us consider now, by order of dates, the solution I presented in 1892 and which was explained in my book, "Panama—Le Passé, Le Présent, L'Avenir," and the solution adopted by the Isthmian Canal Commission in 1901.

Both are inspired by the same conception, both consist in receiving the waters of the Chagres in a large lake formed by a dam at Bohio, and in letting the Chagres waters flow into the Chagres bed below Bohio on the North American side of the canal, which leads them to sea without any more contact with the canal, through its wide and deep channel, rectified in two places, from kilometer 22 to kilometer 16 and from kilometer 10 to kilometer 8.

If the general plan is identical in both projects, the altitudes of the lakes are different. I proposed in 1892 a lake oscillating between 52 feet 6 inches and 62 feet 4 inches (16 and 19 m.). The Isthmian Canal Commission proposed a lake oscillating between 85 feet and 92 feet (25.92 and 28.06 m.). The reason of that difference in the proposed levels can be found in the difference of conception of the two plans.

My project was drawn as a preliminary step toward the conclusion of the sea-level plan. The project of the Commission was a definitive and not a temporary solution. I considered the Bohio Lake in the first phase of the life of the canal as simply a means of expanding at Bohio the Chagres in such a way as to suppress any trace of any current whatever. The Chagres, thus made still and inoffensive, could be tapped on the North American side of the canal and thrown into the bed that remains entirely (except for 5 miles) on this same side of the canal until it reaches the sea.

In other words, the Bohio Lake was in my mind an organism enabling me to bring the Chagres from the South American side of the canal, where its head is, to the North American side of the canal, where its mouth is, without disturbing the navigation in the canal. For this limited purpose a lake oscillating between 16 and 19 meters was ample. It presented the inestimable advantage of requiring a low earth dam easy to build and presenting perfect guaranties of safety.

I admitted freely the waters of the Chagres in the part of the canal between Gamboa and the Bohio Lake proper. I increased the horizontal and vertical dimensions of the canal prism in this section in order not to have more than 2 knots with an 800 cubic meter a second freshet (27,000 c. ft.), and I intended to close navigation in case of one of these rare and short high floods, which might have caused a 4-knot current in said section. The sediments could not stay in the canal bed but would have been precipitated in the Bohio Lake, a danger which I accepted readily in view of the short space of time that this first period was to last. The outlet of the lake was insured by the opening of the gates from the maximum to the minimum level as soon as a tendency to increase of level would show itself.

The conditions in the river below Bohio were not ameliorated by a reduction in the amount of water due to a storage of any importance, but were, however, improved by the reduction of distance between Bohio and the sea resulting from the short cuts.

I contemplated, after this first period, the erection of the Gamboa dam as the essential element of the control of the Chagres floods and of the prosecution of the sea-level plan, but I did not think proper to develop the detailed plans of this prosecution in my book of 1892 on account of the only aim it had then in view—to demonstrate that a paying canal could be established at Panama in a short time and with the amplest margins of safety against any disappointments such as had attended the first Panama enterprise.

The plans of the Isthmian Canal Commission were not drawn for a temporary period like mine, they contemplated a permanent and definitive lock canal. The Commission improved the conditions of the Chagres regulation in my plan by adopting a higher level, a maximum of 92 feet instead of a maximum of 62 feet 4 inches. This was bought at the expense of a higher earth dam, which was not considered by the Commission feasible without a core wall established on a rock foundation supposed then to be at 128 feet below sea level.

The surplus elevation given to the lake surface increased the dimensions of the lake, the waters of which went far above Gamboa, reducing correspondingly the amount of sediments to be expected from the high Chagres. The capacity of the lake, when rising between its minimum and maximum level, to absorb a large volume of water, helped to reduce the floods thrown into the lower river bed between Bohio and the sea. The enlarged dimensions of the lake, even in the neighborhood of Gamboa, allowed to say that the greatest floods would not trouble the transit.

One sees how the defects which were tolerable for a temporary period, but inadmissible for a definitive project, were cured by the surplus elevation given to the lake surface by the Commission, as they had to be for a permanent conception.

THE PLANS OF THE ISTHMIAN CANAL COMMISSION PERFECT FOR A PERPETUAL LOCK CANAL—DEFECTIVE IF TRANSFORMATION TO SEA LEVEL IS CONTEMPLATED.

The other end attained by the Commission was to reach a level which was admissible for a ten years' plan of excavation in the central cut.

As I have already explained it, the solution, consisting in adopting a common level for the lake and the waterway in the central cut, is very attractive on account of its obvious simplicity, but it has the defect of necessitating too high a dam and too deep a cut.

Certainly for a perpetual lock canal one must admit that it is the best solution to be adopted, and that it would justify the erection of a core wall even on foundations at elevation—163 (—53.4 m.), where the rock is found now, instead of —128. But such a solution can not sustain any attentive examination if made from the point of view of an ulterior transformation to sea level. It fails to answer to the essential conditions as to time and as to risk, to which such a project is submitted; it admits of an unnecessarily high and, therefore, of an unnecessarily dangerous dam; it admits of an unnecessarily deep cut and, therefore, of a work unnecessarily long to conclude.

I have finished this part of my exposé, which relates to the first of the two great technical problems of Panama—the Chagres. Let us now turn to the other one—Culebra.

THE CULEBRA PROBLEM.

As you can see on the profile of the canal line attached to the yellow pamphlet entitled "A Solution of the Problem of Panama," this terrible problem, the real great one which ever really existed in the Panama question, vanishes entirely.

No one can say longer, with the plan proposed, that the Culebra excavation is the controlling factor of the time of construction. A mass of about 20,000,000 cubic yards remains to be removed and that is all. According to the standard speed assumed by the Isthmian Canal Commission (5,375,000 cubic yards per annum) this can be done in three years and nine months.

Some of the objections raised against my plan and which can be read at page 224 of the gray pamphlet entitled "Panama Canal, Part IV," relate to the increased number of locks and the difficulty of supplying the summit level with water.

There is an obvious misunderstanding on this point. I never thought, as can be inferred from the text of the remarks in the gray pamphlet, that I did not propose to erect immediately the dam at Gamboa up to level 200. I spoke of level 150 because I thought that the only objection to the four years' time limit might be the difficulty of completing the erection of the dam. I wanted to express the idea that the canal could be opened, even if the dam had not yet reached its ultimate height and was at elevation 150 instead of elevation 200. I never thought a moment that the dam would not be completed immediately after the opening, and that it would remain unfinished at 150 feet elevation for the purpose of elevating the spoils into the lake, as it is stated among the remarks of which I speak.

SUPPLY OF WATER TO SUMMIT LEVEL PERFECT IN THE PLANS I PROPOSE.

I could not discover what could support the statement to be found on said page of the gray pamphlet, that there is in my plan no satisfactory way of supplying the summit level with water. Whether the level of the lake is at 150 feet or at 200 feet elevation, it matters little for feeding the summit level. It seems useless to enter into details about the possibility of sending water from that lake into the inferior summit level at elevation 130 feet when the water of the lake comes naturally within a distance of less than half a mile from the extremity of the said summit level.

There is also in the remarks of the gray pamphlet an evident misunderstanding about the suggestions that I am supposed to have made to feed the summit level with pumps or with a reservoir at Alhajuela. I mentioned the possibility of resorting to such methods simply for the sake of argument in studying the limits put by nature to a lock canal in Panama. I never proposed to feed the summit level that way, otherwise than in a temporary emergency.

In fact, the objections to my plan as raised in the remarks of the pamphlet relating to the system of feeding the summit level and of controlling the Chagres result from a misunderstanding, for which, perhaps, the too condensed way in which I was bound to expose my views is responsible.

However, in the explanation which I made of the method of using the lake as a flood controller and as a water storer I have already explained fully these views on this point. The limit of the oscillations of the lake will be 40 feet, and, as I have said, the surface water will always be between 160 to 200 feet elevation, and therefore will secure perfect access of the lake waters to the summit level at elevation 130 or below.

After answering these objections, let us turn back to the question proper.

WHY LEVEL 130 WAS CHOSEN FOR THE SUMMIT—THE SUMMIT SHOULD NOT BE LOWER IN ANY CASE FOR THE FIRST FORM OF THE PANAMA WATERWAY.

I may very well be asked, why is level 130 chosen for the summit section of the waterway? Because to excavate to that level will mean to remove a quantity of ground which can be disposed of within the time necessary for the rest of the works, and because the small increase in the depth actually excavated limits to its minimum the risk of slides and the corresponding danger of being stopped some years more by such an accident or by the supplementary works which may be deemed necessary for the purpose of preventing it.

It may be also added that it is not advisable to place the summit level higher than 130 feet above the sea, on account of the difficulty of having a satisfactory location for the supplementary lock which would be necessary.

Why would it not be better, might be also asked, to prolong the delay of construction for three or four years in order to dispense with one of the locks ascending to the summit level?

This question might be difficult to answer if the lock canal were built for eternity. It would be a grave question whether, for the benefit of an indefinite future, it would not be better to sacrifice some years more in construction. But if we build the canal with the well-formed idea that it is only a step made in the road toward the sea-level canal, the answer to the question is obvious. In digging deeper we must accept a certain and definite increase in the time of opening

the canal. We retard this long-desired day without any justification except to reduce a little more the time of transit of the ships during the period that will elapse between the opening of the waterway and its ulterior deepening.

This supplementary delay in transit due to the passage through two more locks is a slight temporary disadvantage in operation, which will disappear in the prosecution of the sea-level plan. On the contrary, the supplementary delay of the opening of the great highway is known and will cause serious harm to the world's commerce and perhaps to the defense of this country.

On the other hand, when we go deeper we not only incur new and certain delays, but we incur also new risks as to the stability of the sides of the cut. If a stratum is found which causes a slide, how many other years may be added to the number of those we calculate as the necessary supplement? Deeper digging means more time; it means also more risk.

As soon as the reasonable summit-water height of 130 can be reached, it should not be attempted to go deeper for the time being. Even if the bottom level of 95 feet was actually reached by the works in the past, I should still declare that the Culebra cut being entirely open for the actual project it is better not to attempt to lower it, and that having one of the greatest difficulties finally removed it is inadvisable to introduce it again under the erroneous conception that we shall have a still better canal.

No; a canal at elevation 130 is perfectly satisfactory for the beginning of the operation, and all attempts toward lowering the central passage would mean to disobey the iron rule, which must be kept in mind—to select in every section of the canal the course leading to the minimum of effort and to the minimum of risk, so long as the certain result will be an ample and permanent communication between the oceans.

One might say, also, that the advantage from the delay would result in an economy equal to the cost of two locks. But a couple of locks will mean an expense of five or six million dollars, and the net earnings of only one year of operation will amply cover such an expense.

But it may be asked, also, even if you had to spend seven years for the rest of the works, would you still stay at this same level? I would say emphatically, yes. If the other works were so difficult as to require seven years' time, or even ten years, I should, after completion of the central cut, dispose of its laborers and employ their activities elsewhere to hasten the day of the opening.

The labor question will remain, during the construction, an element of continuous difficulty. The laborers may be scarce; the required number may not be obtained; and this is a new reason to prefer the erection of a pair of locks to excavating a new mass of ground through the central cut. If the labor is not scarce I should prefer employing it to widen the summit cut and to remove the ground above 130 in order to pave the way for the period of transformation.

The erection of a pair of locks consists simply in putting together elements (cement and steel) prepared away from the Isthmus, whereas the digging is a purely Isthmian operation and requires a correspondingly higher number of men.

The advantage of the method of making the sea-level canal in two phases is to insure the most rapid execution of the waterway first and to realize the necessary improvements afterwards. It draws a clear line of conduct which prevents the mixing up of two different desiderata, utility and perfection.

The first phase corresponds to utility and leads to the simplest form of a canal that insures permanent and ample communication. In other words, the first phase corresponds to the minimum of resistance, and the second to the maximum of perfection.

The conception of a summit level at 130 is, for the section considered, along the line of least resistance, and therefore any attempt toward a lower passage for the first phase at the cost of additional delay, or at the cost of an additional risk, should be discouraged.

Such a step would be against the indications which the President of the United States has recently made, with his high authority, as to the principles which should guide the researches of the Consulting Board. "I hope," he said, "to see the canal constructed on a system which will bring to the nearest possible date in the future the time when it is practicable to take the first ship across the Isthmus." He said also: "The delay in transit of the vessels owing to additional

locks would be of small consequence, when compared with shortening the time for the construction of the canal or diminishing the risks of the construction."

The adoption of a level lower than 130 would be in direct contradiction with the principle which the President, speaking in the name of the national and international interests, has so happily, so clearly, and so authoritatively expressed.

Third Part.

TRANSFORMABILITY OF THE CANAL BUILT WITH LOCKS INTO A SEA-LEVEL WATERWAY.

I hope to establish to your entire satisfaction that, thanks to a very insignificant alteration in the usual type of locks, this transformation can be obtained gradually, without interrupting the international navigation at all.

I hope further I will establish to your entire satisfaction that, if the dimensions of the channel bottom are increased from 150 feet, as actually projected, to 300 feet, this transformation can be made, not only without any interruption of international navigation, but also without any contact whatever between the international navigation and the instruments of excavation and of transportation of the spoils. During all the period of transformation the channel of international navigation will remain completely free from anything which is required for digging as well as for transporting the spoils.

The freedom of this international navigation channel will not be affected by the transformation, if the channel bottom is doubled, any more than if the works were executed in another part of the earth.

If the channel is not doubled, if the same width of 150 feet is not modified, this complete independence will be maintained for all the works from level 130 down to level 75, which means about half the mass to be extracted. From level 75 to sea level, the works would have gradually more and more to be executed within the limits of the navigation channel of 150 feet.

But even so, they can be prosecuted so as to leave always free and independent, for international navigation, a channel of at least 75 feet width; that is to say, a channel sufficient for nearly all the ships of the world, a channel of a width equal to that which was considered ample at Suez for many years, a channel equal to that which was projected by the old Panama company for the sea-level canal, a channel superior in width to that of the actual Kiel Canal channel.

It may be further said that the contraction down to 75 feet of the channel reserved to international navigation is the extreme reduction, and that it would happen only on the very last period, when the sea level will be reached.

Under the hypothesis of no increase of the channel width, the channel devoted to international navigation and completely free from all instruments of work will remain larger than the standard 150 feet width above level 75, and will begin to be contracted from level 75 on. From level 75 to level 43 the free channel will be gradually contracted to 118 feet; that is to say, to the dimensions adopted by the Comité Technique in 1898, and which offered a very satisfactory and ample waterway.

It is therefore in the last period, for the last 43 feet, that the contraction would gradually decrease the width of the free channel from 118 to 75 feet.

In the remarks preceding my letter to the President, and to be found on pages 223 and 224 of Part IV of the gray pamphlets prepared for the Consulting Board, it is stated that the proposition of doubling the bottom width of the channel is made for the purpose of avoiding the contraction of the channel; that it would lead to "extravagant cost and is believed to be unnecessary."

THE INCREASED WIDTH OF 300 FEET AT THE BOTTOM NOT RESULTING IN AN "EXTRAVAGANT COST."

It has been far from my mind to say that such increase of the bottom width would have for its sole purpose to avoid contraction of the channel during the transformation. I have undoubtedly not expressed my conception in the letter to the President with sufficient clearness. I am going to express it in a different way:

When the moment comes of determining upon the transformation, this decision may be due to two different orders of considerations. It may be due to the pressure of the increasing traffic and to the foreseen necessity of handling, within a limited number of years—ten or twenty—a traffic having an importance comparable to that of the Sault Ste. Marie Canal, or of that passing before Detroit. It may be due also to the purely moral or military consideration of having a canal without artificial works save a tidal gate, without any pressure from the traffic.

Upon the first hypothesis it seems to me inadmissible that the improvement to be obtained by the suppression of the superior levels will not be accompanied by a corresponding improvement in the width of the channel bottom, and I fixed 300 feet as the probable minimum which will then be adopted.

Under these probable circumstances I wished to establish that the transformation will be made without any restriction upon the unhampered use of the standard bottom level now admitted. I did not consider the increase of the bottom level as necessary for the execution of my plans. I simply said that if it were ordered for the higher consideration of traffic development the effect would be the one I tried to show.

I do not, therefore, think that it is justifiable to say that the cost resulting from the method I recommend would be extravagant, because the cost does not apply to the method, but to the end supposed to be in view—to have at the same time a sea-level and wider waterway.

This conception of the future necessity of increasing the bottom width of the canal is not limited to me. It can be found very clearly expressed in one of the other gray pamphlets prepared for the Consulting Board, namely, on page 197 of Part III, entitled, "Sea-Level Plan." In anticipation of the future necessity of increasing the width and depth of the canal, it is recommended there that, if a sea-level canal construction is contemplated at once, a supplementary excavation should be made immediately, to satisfy the eventual need of enlarged dimensions in the navigable prism. It is for that purpose recommended there to widen the berms 50 feet on each side; that is, to increase the width of excavation above the berms by 100 feet, which leads to a supplementary excavation of 36,320,000 cubic yards before any operation of the canal.

This provision to make immediately above the berms the works necessary for a future increase of the channel width by 100 feet corresponds, I may say, exactly to my proposition, and there is no real difference between supposing that the demanded increase would be 100 feet and supposing that the demanded increase will be 150 feet.

If the stigma of "extravagant cost" were applied with justice to the proposition of increasing by 150 feet the width, it applies also to that of increasing it by 100. The two-thirds of an extravagant cost is still an extravagant cost.

If the increased width of the canal should be decided to be only 100 feet instead of 150, it can be established that the international navigation will retain the constant and unhampered use of a channel larger than 150 feet until the summit level has been lowered down to 25 feet above sea level and that it will be gradually restricted down to 125 feet, which will be the inferior limit of contraction of the free channel by the works. This will only happen when the sea level is reached, to be followed immediately by the enjoyment of a 250-foot channel.

If we remark that the bottom width of the Suez Canal is 115 feet, that of the Manchester Ship Canal 114, that of the Amsterdam Canal 118 feet, and that of the Kiel Canal 72, we must express the opinion that the restriction of the free channel down to 125 feet during the very last period of the work of transformation will not in the least interfere with the free transit of international navigation.

We shall, however, continue to argue on a supposed increase of width of 150 feet in case of an enormous traffic in sight, because it seems to me better justified than an increase of 100 feet, and also because the difference in cube between 100 feet increased width and 150 feet increased width would amount only to about 18,000,000 cubic yards above the berms between Bohio and Miraflores, or to about 28,000,000 cubic yards down to the bottom level. This is a mass of excavation relatively secondary compared with the total amount to be removed, and which will be fully justified by the facilities afforded to passage of ships across the Isthmus in the sea-level canal.

INTERNATIONAL NAVIGATION TO PRESERVE AN INDEPENDENT CHANNEL OF AT LEAST 75 FEET IF NO INCREASE IN THE WIDTH IS ADMITTED.

In the second hypothesis I have made, if no increased width accompanies the transformation on account of the slackness of traffic, I can say that international navigation will not be hampered by a contraction of its independent channel down to 75 feet.

The contraction is not really a strict one; it means only a delimitation of the fields where no machines, dredges, scows, tugs, etc., will ever be allowed to enter; but in case the international navigation needs it, it can take the channel devoted to works; dredges will go on one side and let ships pass.

The Suez Canal has been widened and deepened with an original bottom width of 72 feet, and international navigation was never stopped by the working instruments.

It can be therefore stated that even without increasing the width of 150 feet the transformation can be done, without any harm to the international navigation, but it can not be said any more that the work will be done without borrowing one inch of the standard channel devoted to international navigation.

I shall, however, continue to use this rule, because it expresses in a few words the character of the proposed method and because it corresponds to the most probable case—the doubling of the width under pressure of the increase of traffic.

Not only can the works be prosecuted without borrowing an inch of the standard width of the channel devoted to international navigation, but also they can be prosecuted without employing one minute of the time of the locks devoted to international navigation, and also without spending one drop of the water stored for the use of international navigation.

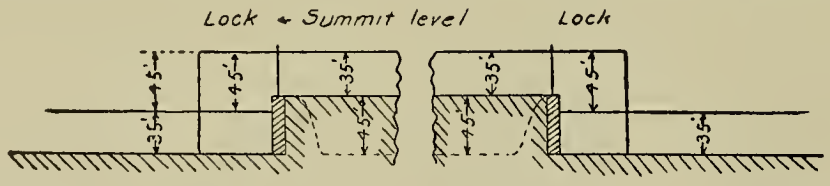
If I establish these three points I shall have established that my method meets the three conditions which are necessary and sufficient for allowing the transformation to go on without any limitation whatsoever on the activity and on the freedom of international transit.

BASIC PRINCIPLE OF THE SYSTEM OF TRANSFORMATION.

It consists in a modification of the ordinary type of locks.

Single lock.—Let us examine a single lock, and let us suppose a depth of 35 feet in the canal and a fall of 45 feet for the locks.

In the ordinary type the upper gate of the lock has a height equal to the depth of the canal and it is seated on a wall. This wall plays two different parts in the structure: It serves as the basis of the gate and at the same time it serves as a retention wall for the ground of the higher level.



Let us examine the conditions created by the ordinary type of construction of lock in a canal with a summit level.

It is obvious that to remove the summit level with the least inconvenience it will be necessary first to excavate by floating dredges the ground of its bottom down to the level marked by dotted line, and for that purpose to dredge down to the abnormal depth of 80 feet. This being done, it will be necessary to interrupt navigation in order to remove the locks on both sides, because the locks can not be touched as long as transit is going on.

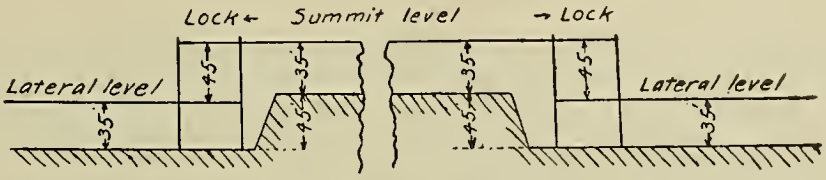
These explanations being given, let us come to the solution I gave to the question:

It simply consists in giving to the gate above the lock exactly the same height as the gate below, and the same level of foundation.

Of course, the ground forming the bottom of the summit level will have to be excavated down to the level of the bottom of the adjoining navigable level for a distance of 400 or 500 feet above the gate of the lock. It can not be any more limited by the wall which in ordinary locks supports the gate above.

The locks being so disposed, if we dredge 5 feet into the bottom of the summit level we shall not touch, during such dredging, any vital part of the canal, and the locks will remain exactly as they are.

When the dredging is finished, as we have 5 feet too much depth of water in the summit level, nothing prevents us from letting the level of the water drop 5 feet. When this is done the ships will still find the 35 feet depth of water they require, and nothing will have been changed, except that the canal will have then its summit 5 feet lower above the level of the sea than before.



After nine successive operations of the same order the level of the summit will be lowered 45 feet, and the gates of the locks, being from now on useless, can be removed. The summit level being removed and confounded with the two lateral ones, the new summit level can in its turn be excavated by the same process.

It is obvious that for the removal of this new summit level the masonry of the old locks after removal of their gates will be nothing but a mass of rock in this new summit level. The removal of this mass of artificial rock will be handled exactly as any other rock which may be found anywhere else in the summit level.

I scarcely need say that I do not attach any importance to the particular dimension of 5 feet, which I have chosen only for the sake of the exposition of the theory. The transformation may go on just as well if 10 feet or 15 feet deepening at a time is adopted as being more favorable for the work of the dredges.

It is obvious that the advantage which results to the transformation from the suppression of the wall is a consequence of the fact that with it disappears a hybrid organ which belongs at the same time to the lock and to the summit level.

During all the digging of the summit level the lock must remain in its absolute integrity to insure the passage of the ships. Therefore, the retention wall limiting its bottom must be attacked, as all the elements of the summit level if the bottom of the summit level is lowered, but that can not be permitted, because the wall, if attacked, would make the lock useless on account of the second part it has to play.

By suppressing in the proposed method an organ common to two entities having contrary requirements, we suppress at the same time the capital obstacle to the transformation, an obstacle which has led many engineers to contend that such a transformation is impossible without stopping navigation.

IT HAS GENERALLY BEEN THOUGHT THAT IT WAS IMPRACTICABLE TO LOWER THE LEVEL WITHOUT STOPPING NAVIGATION.

The expression of this erroneous opinion was recently embodied in an official document signed by the chief engineer of the Isthmian Canal Commission, Mr. John F. Wallace, in his report of February 1, 1905, directed to Rear-Admiral John Walker (p. 25 of the green pamphlet):

> It is evident that the construction of a dam at Bohio and the creation of an artificial lake will introduce an element into the problem which would render any future reduction of the summit level impracticable, considering the time and cost and the possibility of the canal being closed to traffic for a number of years during the process.

The Bohio Lake, when it will have been confounded with the summit level—that is to say, when the upper summit level will have disappeared—will be only a wide part of the new summit level. When the summit level to which it belongs shall be gradually reduced in altitude the Bohio Lake will gradually become lower, as any other part of the summit level whether wide or narrow. The presence of a widened part in the level can not by any sort of consideration be considered as bringing even the shadow of a difficulty into the problem.

The Bohio dam, on the other hand, will not have to be removed when the canal will become sea level, contrary to what is said on page 224 of the gray pamphlet, Panama Canal, Part IV.

THE CANAL, WHEN SEA LEVEL, WILL RECEIVE THE HIGH CHAGRES WATERS, CONTROLLED AND CLEANED, FROM THE GAMBOA LAKE, AND THE CHAGRES TRIBUTARIES WILL FLOW INTO THE CANAL DIRECT BETWEEN GAMBOA AND BOHIO—NO FURTHER TRIBUTARIES TO BE RECEIVED BELOW BOHIO.

I believe that with the increased controlling power of the Gamboa dam, owing to the suppression of the necessity of feeding the summit level, as it has been explained, and on account of its faculty of absorbing entirely any great flood, one may safely admit that it will keep back during every exceptional flood all the waters of the upper Chagres, even if they are much more violent and much more durable than the one of 1879.

Under these conditions the canal, with its enlarged dimensions of 300 feet at the bottom, can receive all the water that the tributaries send to the thalweg between Gamboa and Bohio. This is known to have been at the maximum equal to 1,000 cubic meters (33,000 c. f.) per second in the greatest known flood, and that it will give a current inferior to 1 knot in the canal with its enlarged dimensions.

Below Bohio the deviation already made on the North American as well as on the South American side of the canal will continue to carry to the sea direct the tributaries of the Chagres below Bohio. The only difference will be that the one placed on the North American side will no longer receive any water from above Bohio. It will therefore be largely superior to any needs about the passage of the floods of the tributaries, the largest one of which is the Rio Trinidad. The deviation on the South American side of the canal will not receive any important tributaries before the Gatuncillo, which falls in front of kilometer 10 on the canal line. At such a small distance from the sea the deviation can be made of such width that a rise of 3 feet will absorb any imaginable flood of the Gatuncillo. For these two reasons, on the North American or on the South American side of the canal, the deflected tributaries will be absolutely incapable of raising their level as high as the natural ground, and no overflow may any more be thought of.

After the high flood shall have disappeared the Gamboa dam will spill the retained waters in the canal so as never to produce more than a total flow of 33,000 cubic feet (1,000 c. m.) in the canal and not to generate a current superior to 1 knot.

If no deviations are wanted between Gamboa and Bohio, the earth dam of Bohio will remain undisturbed as a witness of a bygone period, but will not have to be removed. The only objection to this disposition might be the sediments brought by the tributaries falling into the canal direct between Gamboa and Bohio. Some works might decrease the sediments of these small rivers. If they prove to be excessive, which I do not believe to be the case, they can be led by deep deviating channels to the deviations existing in the low valley between Bohio and the sea.

Locks in flight.—Let us now see what must be done with the locks if, instead of being isolated, they are disposed in flight of two locks, which corresponds to the case of my project.

For the upper lock there is no difficulty. Its treatment will be exactly what it would be were it isolated. The difficulty begins when the upper lock is removed, because the lower lock presents itself naturally as a lock constructed according to the usual type. The lower gate of the upper lock becomes the upper gate of the lower lock and is seated on a wall limiting the bottom of the lock.

Let us consider a flight of two locks having the same fall of 45 feet as we have already considered, and let us suppose it to be placed at the extremity of a summit level.

The two following sketches represent the flight before the transformation and the flight after the upper lock has been erased and the summit level lowered 45 feet.

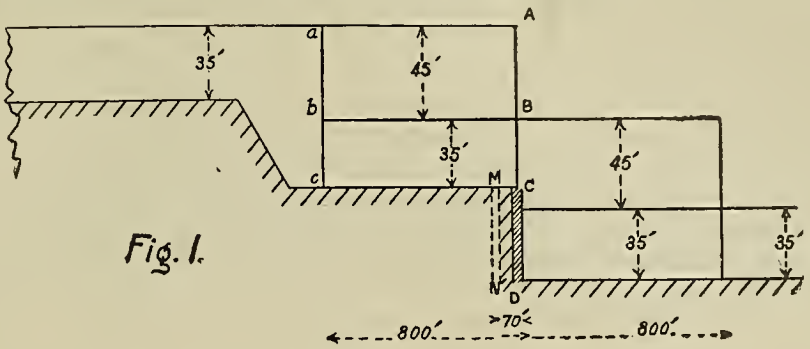


Fig. 1.

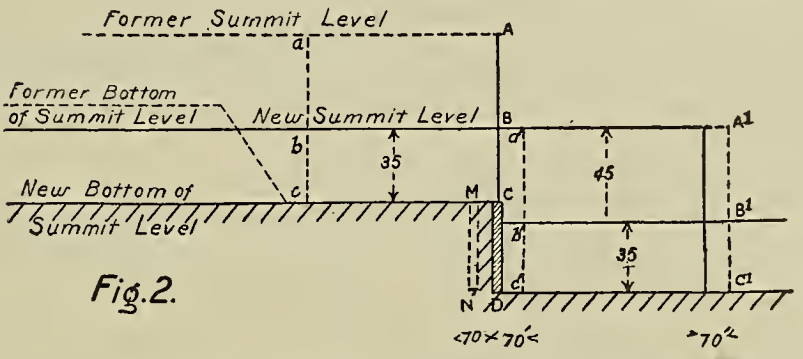


Fig. 2.

The same principle which we laid before will lead us to the solution. We must liberate from one another every organ of the summit level and every organ of the lower lock.

A first solution similar to the one already described appears at first glance.

If, instead of building the lower gate of the upper lock from A to C we make a gate extending from A to D, and if we limit the bottom of the upper lock by a wall placed in M N instead of C D (the distance between C D and M N being about 70 feet), we shall have reproduced the conditions described for the single lock. [a]

When the upper lock will have been razed, its bottom will form the extremity of the new summit level, and this extremity being free from the upper gate of the lower lock and at a distance of 70 feet, can be, like the rest of the summit level, gradually lowered without affecting the lock in any way.

Some more precaution only will have to be taken to prevent any stone from falling near the gate. It is useless to insist upon these details; every engineer conceives the precaution for hammering the masonry and carefully taking away the débris, not with dredges but with movable compressed-air caissons or divers. It is sufficient that a distance of 70 feet be reserved between the wall and the gate to prevent any accident through neglect.

This solution has the great disadvantage of requiring the construction of a gate of abnormal height: 45+45+35=125 feet. Therefore, we only mention it for the purpose of following the trail of the principle.

A much better solution can be had by prolonging the lower lock for 70 feet. This enables us to prepare all the masonry and the place necessary for the installation of two gates respectively 70 feet ahead of the two corresponding gates of the lower lock.

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[a] The working capacity of one single lock is nearly twice as great as that of a flight of two locks of the same dimensions. (See my book of 1892.) When the upper lock will be no more useful, one of the twin single locks remaining will accommodate as much transit as the twin flights before, thereby giving all facilities to remove the masonry of one of the upper locks, while the lower lock of the other flight will do all the work of the transit.

After the suppression of the upper lock we place in a^1 b^1 c^1 the former upper gate of the upper lock a b c. This gate being placed the gate A B C becomes superfluous, and may be displaced and put in A^1 B^1 C^1. This new gate being in place the lower gate of the lower lock becomes useless and is removed. The new gates, a^1 b^1 c^1 and A^1 B^1 C^1, being in place, the lower lock becomes entirely independent of the summit level again, and its extremity, which is the wall C D, is at a distance of 70 feet from the upper gate. It can therefore be excavated as it has been explained before, with the same treatment as the rest of the summit level, except for the necessary precautions due to the proximity of the upper gate of the lock.

This arrangement is perfectly simple, perfectly feasible, does not require the building of abnormal gates, and is limited to a single precaution in the drawing of the plans of the locks and to the surplus expense resulting from a prolongation of the inferior lock by 70 feet.

ESSENTIAL CONDITIONS OF THE TRANSFORMATION.

Having thus established the basic principle which allows the transformation from lock canal to sea level to be prosecuted without interruption to the international navigation, I have now to establish that it meets three essential conditions required for it to be above any criticism. I have to establish that the process does not touch the three essential elements of such navigation.

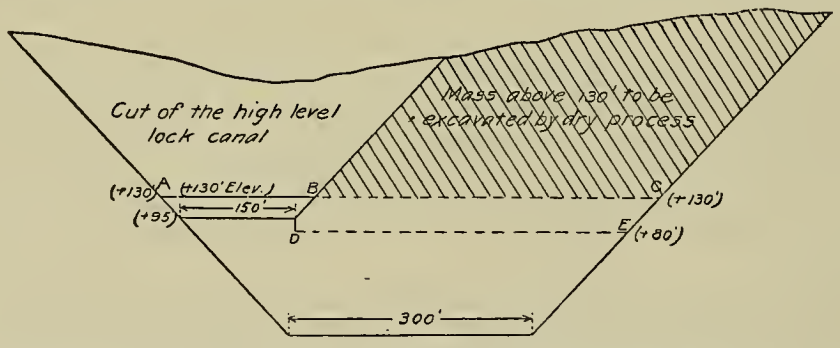
1. The width of the canal.
2. The locks of international navigation.
3. The water stored for feeding the summit level.

NOT ONE INCH OF THE CHANNEL DEVOTED TO INTERNATIONAL NAVIGATION WILL BE USED BY THE WORKS OF TRANSFORMATION.

We shall establish this first proposition under the admission that the width of the sea-level canal will be fixed at 300 feet instead of 150 feet.

I have explained before that if the increase of width is 100 feet instead of 150 feet, we must understand the proposition in that sense that the channel of international navigation will be limited to a minimum of 125 feet during the period of transformation from level 25 to sea level, and that if no increase of width at all is admitted, there will be a gradual contraction of the channel devoted to international navigation from 150 width to 75 width during the period attending the lowering of the summit level from the altitude 75 to the sea level.

The same demonstration we are going to give upon the hypothesis of a channel bottom increased from 150 to 300 feet can be repeated exactly for any other dimensions admitted between 150 feet and 300 feet, but will lead in every case to contraction of the channel during a part of the process.



The excavation to be executed when the prosecution of the sea-level plan is adopted would consist naturally of the ground above the 130-foot level and of the ground below.

Nobody can see any reasonable difference, for the ground above, between the conditions of excavation which are to-day existing and those which would exist then. The same steam shovels would be employed, the same tracks would be laid, the same locomotives would pull the same

trains to the same dumps. Nothing would be changed except a little prudence in the blasting to avoid damage to the ships; but, as I have shown in my letter to the President, even with the enormous transit of 35,000,000 tons, there would not be more than one passage of ships in each direction every two hours. The limitation of the hours of blasting due to such rare passages is practically immaterial and can have no influence whatever on the rapidity and on the price of excavation.

This very important part, therefore, of the total excavation (the ground above the 130-foot level) can be executed under the same conditions which are to-day contemplated, or even under much better conditions, if the art of engineering makes, as we shall see later on it can, a decided progress upon the methods actually known and on which this statement is based.

Let us now consider the ground below the 130 level. This ground will be excavated by mining and then dredging. The mass of earth above 130 being removed, the ground below may be attacked down to 80, and the first slice of ground between 130 and 80 opened on the side of the navigation channel from B to C.

In order to prevent any contact between any of the instruments of work—dredges, mining and stone-breaking apparatus, scows, tugs, etc.—a first channel will be opened between B and C with the depth sufficient for the circulation of the floating apparatus and in order to give access to the dredges. Such a channel may be opened by dredges or from the surface of B C by excavators working below the surface of the ground.

In any case, neither for the installation of the working dredges nor for the circulation of the scows, will it be permitted to use the channel from A to B, which will be from the first day to the last of the first period we speak of reserved for the circulation of the interoceanic shipping. Therefore it is obvious that during all this work there will be no contact whatever between the mining or dredging apparatus and the navigation channel.

When this new channel, 50 feet deep, shall have been opened, we shall shift the navigation tracks into it; the ships will abandon the old channel, which in its turn will be mined and dredged to the level 80.

At this moment the whole section from A to C will have a depth of 50 feet; the water will then be dropped 15 feet and the navigation channel will be brought again toward the left-hand side of the cut, as it was originally.

The ground which remains free on the right-hand side will be again mined, dredged, and so deepened 15 feet again. The navigation channel will be shifted again to the right and the navigation channel excavated, and so on.

I think this demonstration is perfectly sufficient to exclude any objection about the perfect theoretical, as well as practical, compliance of the method I propose with the first of the three conditions which it has to fulfill. Not an inch of the standard channel is used for the work.

The two other conditions are met by a simple way of disposing of the spoils; we shall therefore examine them both at the same time.

NOT A MINUTE OF THE TIME OF THE INTERNATIONAL NAVIGATION LOCKS, NOT A DROP OF THE WATER STORED FOR THE INTERNATIONAL NAVIGATION, WILL BE USED FOR THE WORKS OF TRANSFORMATION.

If the problem of mining and dredging the ground can be solved, as we have seen, in such a manner that the international navigation will keep the constant use of its standard channel without any contact with the works of excavation nor with the instruments of excavation, the other and not less important problem of transporting by water and disposing of the dredged material can receive an equally perfect solution.

The lake formed by the erection of the Gamboa dam will have a surface of 14.9 square miles at 132 feet of elevation and of 43.3 square miles at 200 feet of elevation. It would hold many times the quantity of ground to be dredged during the transformation from the high-level lock canal into the sea-level passage.

It may be stated that the quantity of ground to be dredged between the Obispo and the Paraiso flights of locks for the transformation would be approximately 70,000,000 cubic yards if

the bottom width of 150 feet should be maintained, and of 110,000,000 if the bottom width of the sea-level passage is brought to 300 feet (admitting a theoretical cross section 150 feet at the bottom, with 45° slopes, in order to get an approximate idea of the time required).

The mass of 70,000,000 cubic yards, if it were distributed on a surface equal to that of the lake at 132 feet elevation, namely, on 14.9 square miles, would form a deposit about 5 feet high. A mass of 110,000,000 would form a deposit about 8 feet high. It is easy to imagine how many times this lake, which will be 145 feet deep near the dam, will furnish room for the dumping of the dredged material.

GAMBOA LAKE, ALREADY A FLOOD CONTROLLER AND A WATER STORER, TO PLAY A THIRD AND MOST IMPORTANT PART—IT WILL RECEIVE ALL THE SPOILS OF THE GREAT CUT.

The solution I propose consists in disposing of the dredged ground by dumping it in the Gamboa Lake.

This solution can be easily realized by connecting the waters of the lake with those of the summit level by a double flight of five locks. The material extracted by the dredges would be dumped into scows, which would go along the summit level, in the channel opened outside of the navigation channel, and after ascending the flight of locks, enter into the Gamboa Lake and simply unload themselves by opening their bottom gates.

This would be the most ideal method of excavation, the most simple, and the only one necessitating no intervention at all of the hand of man, and the total execution by powerful, simple, purely mechanical methods.

The extreme simplicity of the solution, as well as the power of its elements, will be shown by the fact that only eight dredges working in the summit level (about 8 miles long) would dispose in seven years of the 110,000,000 cubic yards corresponding to a sea-level passage with 300 feet at the bottom, and in less than five years of the 70,000,000 cubic yards corresponding to a sea-level passage of 150 feet as it is actually contemplated.

COMPUTATION OF TIME OF TRANSFORMATION A CONSERVATIVE ONE.

The type of dredge on which these calculations are made is the one I already referred to when speaking of the Bohio dam—a dredge having buckets of 1 cubic yard capacity, a theoretical excavating power of 22,000 cubic yards in twenty-four hours, and a practical output of 6,500 cubic yards measured in the excavation. Very likely the size of the buckets would be still largely increased; there is no practical limitation to that, owing to the indefinite power of the water to carry heavy machinery.

The output of the eight dredges would reach 52,000 cubic yards a day, or about 2,000 per hour. Therefore three scows only, holding 750 cubic yards or more, would pass every hour through the locks, which, if taking four at a time, would remain far below their working capacity. By this solution the transportation and dumping can be obtained without leaving the summit level otherwise than by the flight of locks ascending to the Gamboa Lake.

The locks for the international navigation will therefore remain entirely free from any service necessary to the excavation of the sea-level canal, and, like the channel itself, will remain completely independent of these operations.

The water necessary to lift the scows to the lake and to return them will fall into the summit level and will form only a fraction of the flow that it will be necessary to send from the lake into this summit level in order to feed it; in fact, it is not the water that will be utilized, but its mechanical power to raise the scows. The locks, the channel, and the water devoted to the international navigation will therefore remain entirely free from the works of transformation.

The transformation in five years, if the bottom width is preserved, or in seven years, if the bottom width is doubled, would of course be realized provided the ground above level 130, which will have to be excavated, partly at least, by steam shovels on rails, is removed beforehand. It seems logical to admit that this excavation will be ordered before the sea-level transformation is decided, and that the ground would be free at this moment unless, as will be seen later,

it is thought advisable to enlarge very much the sea-level passage, in which case the transportation to the dumps of the ground above level 130 will be effected by scows ascending into the lake.

A cheap and quick method of excavating the ground above 130 would be to unload it into the partially opened channel B C (see diagram, p. 226) with the Brown transporting-hoisting machines, or similar appliances, then to dredge it and load it on scows.

It must be also remembered that the excavation between Bohio and Obispo on the Atlantic side, and between Paraiso and Miraflores on the Pacific, will have to be prosecuted as soon as the summit level will be brought down to elevation 60. This will only mean an addition of dredges in these two sections. The locks, as we propose to make them, will always have a surplus power to raise scows which is much larger than will be necessary to make the seven years' plan of transformation a reality.

SIZE, LOCATION, AND COST OF THE LOCKS UNITING LAKE GAMBOA TO SUMMIT LEVEL.

It remains for me to show how the locks ascending into the lake from the summit level will be established, what will be their arrangement, location, and cost:

There will be two chains of five locks, one for ascending, one for descending. Each lock will have 40 feet fall, a useful length of 450 feet and a useful width of 85 feet, and a depth of water at the low stage of 15 feet. They will be able to take in one lockage four scows 200 feet long, 40 feet wide, and drawing 14 feet of water. Such scows can take easily 750 cubic yards measured in the excavation; each lockage therefore will lift 3,000 cubic yards.

As it may be admitted that a lockage will last a maximum of forty-five minutes, the output will be 4,000 cubic yards an hour, or 96,000 cubic yards every twenty-four hours. This would correspond to a production of 30,000,000 cubic yards a year, and insure the accomplishment of all the work to be done below 130 between Gamboa and Paraiso in three or four years, with the increase from 150 feet to 300 feet of the bottom width, admitting a cross section consisting simply in 45° slopes on the side for the purpose of general valuation only. It would be necessary to obtain such production to place one dredge every half mile, or 16 in the summit level.

The lockages will not take more than half an hour; there is, therefore, an ample margin of safety if we base our calculation on forty-five minutes. It will cover amply the time eventually to be lost by an accident to the locks. Such an accident would have no bearing on the operation of the canal; it would paralyze the excavation, of course, but the cost of such interruption would be small, on account of the very limited number of men employed. The probability of such a delay can be estimated from the operation of great lock canals. It is insignificant, compared to the margin of safety of one-third we allow to cover it.

Such an extraordinary capacity of supposed production is not like what results from the supposed development of a large system of steam shovels, railway trains, and dumps. The defect of these large combinations is that they want a very able body of coworkers to make them a success, and this is and will be always wanting on the Isthmus. Outside of that, every instrument of work is depending on its neighbor. A derailment or landslide will paralyze a series of trains and leave idle for long hours 10 to 15 steam shovels.

EXTRAORDINARY SUPERIORITY OF EXCAVATION ON WATER COMPARED WITH DRY EXCAVATION.

On the water every instrument is perfectly independent of all others. An accident, if it happens to one, does not affect ten or fifteen. An accident on the water is exceptional, but in the dry excavation they are the normal rule on account of the condition of the tracks on which they must be executed.

On the water there is not the terrible difficulty of handling a large number of heavy trains on tracks that can not be ballasted; on tracks which have to be moved and shifted every day, as the works progress; on tracks where drainage is impossible on account of the provisional character of their establishment, and this in a country of diluvial rains during three-quarters of the year; on tracks which would require very heavy rails to increase their resistence, but where heavy rails can not be easily used on account of the want of strength of the colored laborers.

On the water the production grows in direct proportion to the number of the elements brought in action. With dry works it is far from being proportional, and the individual efficiency decreases rapidly with the increase of the elements associated together, owing to the repercussion of their accidents on each other. This is so true that I have myself been led to reduce the number of dry excavating machines in order to increase the total output.

GOOD FOUNDATIONS ASSURED FOR THE GAMBOA LOCKS.

The location of these locks is easy to be found near the Cerro Corrozita, where the summit-level locks will be placed on the Atlantic side and which is not more than one-third mile distant from the waters of the Gamboa Lake.

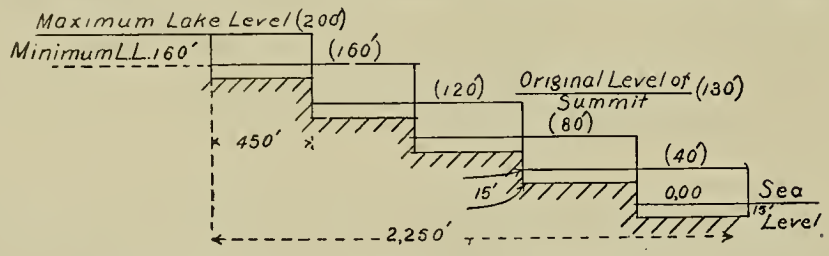
It has been said, in the gray pamphlet, Part IV, among the remarks preceding my letter to the President, that the foundations might not be found. There is nothing of that sort to be feared; the Isthmus around the Gamboa bend of the Chagres is the hardest part of the whole isthmian formation. Everything is rock or rocky clay of the most solid character. There is no risk whatever of not finding the proper location alongside one of the hills connected with the Cerro Corrozita between kilometers 46 and 47.

HOW TO AVOID DIFFICULTY OF CONSTRUCTING THE LOW GAMBOA LOCKS WHEN SUMMIT LEVEL IS REDUCED.

One question has also been raised, about the practicability of building the locks as the level of the summit gradually decreases.

There would be no difficulty at all from an engineering standpoint in constructing these locks under protection of cofferdams, or by compressed air, but this would for a long time paralyze the operation of the locks above. For reasons of economy and of speed it is therefore necessary to avoid constructing the lower locks during works of transformation. It is necessary to include the construction of the three lower ones in the programme of the immediate works. They will be constructed at once under easy conditions and everything will be ready for the day of service except the gates. The two upper ones may be left for the future to take care of, as they will be above the water level of the summit. The summit lock will have on the lake side a variable level between 160 feet and 200 feet. The minimum level of the lake will correspond to the momentary suppression of the utility of the lock as a lock, but will not prevent the passage of the scows, which will still find the necessary depth of water in the lock without the necessity of going through the process of locking.

There will, therefore, result no inconvenience from the variation of the level of the lake for the continuous passage of the scows from the summit level into the Gamboa Lake and vice versa.



COST OF LAKE GAMBOA LOCKS NOT TO EXCEED $15,000,000.

We may estimate the extreme cost of these locks by comparing them with the locks of the Comité Technique. They are of about half their length, the depth of water when the lock is at low stage is also about half that of the Comité Technique's locks, the fall is greater by one-third, the width is about equal.

It may be said that under such circumstances it will be very conservative to take the Comité Technique's figures as representing the probable cost of these locks. It is a maximum valuation

which leads to an expense of $15,000,000 for the two flights of five locks, which, of course, will form a part of the unit price of excavation. Though it leads to a charge of about 12 cents at most per cubic yard on 110,000,000 cubic yards to be excavated below elevation 130 on the distance of the first summit level, a charge which will diminish with the amount of excavated ground passing by the locks, this expense is absolutely justified by the exceptional simplicity of the method of handling the spoils.

I have thus established that the system of transformation recommended conforms well to the necessary conditions enumerated, and respects entirely the width of the standard channel, the time of the international navigation locks, and the water necessary for international transit.

It remains for me now only to speak of the character of the works to be prosecuted by dredging.

SUBSTITUTION OF DREDGING FOR DRY EXCAVATING DURING THE PERIOD OF TRANSFORMATION.

Outside of its general justification it may be asked if the proposed method of dredging is intrinsically better or worse than dry excavation. In other words, are the advantages of the transformation bought at the expense of a surplus of expenses or difficulties due to the method of excavating which results from the character of the transformation itself?

PRINCIPAL REASONS WHY THE WET METHOD IS SO SUPERIOR TO THE DRY ONE FOR EXCAVATING ON THE ISTHMUS.

In all countries of the world dredging is incomparably superior to dry excavation when the ground necessitates no mining. On the Isthmus of Panama this advantage is transformed into an enormous superiority. If there is an instrument of work which counterbalances as much as it is physically possible all the evil influences of the Isthmus it is the dredge. It counterbalances them because, first, it is the only excavating instrument where the white man can work without expense of physical energy, where he can work seated, so to speak, protected from the sun, protected from the rain. Second, because it is the only instrument where the colored man remains under immediate supervision, where he is attached to tasks always the same and under the eye of the overseer. Third, because it is the instrument least liable to suffer from an error or an accident. If a little slide comes it withdraws and is not buried as an excavator or a steam shovel. If the attack of the ground is too hard it simply stops instead of risking to lose its equilibrium; it does not derail; it is free, and its work is not hampered by accidents incident to cars, locomotives, or tracks serving it in combination with other instruments of dry excavation.

DREDGING WAS PREFERRED TO OPEN-AIR ROCK EXCAVATION DURING THE OLD PANAMA COMPANY'S WORK, WITH MUCH LESS POWERFUL DREDGES THAN ARE NOW USED.

Anybody who has worked on the Isthmus with the two systems can not but be struck with the enormous superiority of the dredge. It is so apparent, so obvious, that I did not hesitate at Culebra, as soon as the conditions became compatible with a dredging plant, to endeavor to substitute the work of the dredge for that of dry digging, and this in a hard clay that necessitated the employment of explosives for the work of excavating machines.

THE SUSPENSION OF DREDGING AT CULEBRA A FATAL MISTAKE OF THE NEW PANAMA CANAL COMPANY.

Unfortunately the plant was just in action when the collapse of the old company came; but, however small had been its period of activity, perhaps a couple of months, the result completely confirmed my expectations and fulfilled my hopes. Unfortunately for the canal, the inevitable and blind reaction which followed such a disaster as that of the Panama enterprise put into suspicion the clearest results obtained. I consider that it has been, among others, one of the most fatal mistakes of the New Panama Canal Company not to continue in the same line of effort. What they have done in the Culebra cut would have been infinitely cheaper and quicker done if they had followed my last plans and not simply continued dry excavations, which I had put in

action for a much longer period than the wet process. Since that time no more dredging has been done on the Isthmus, and, therefore, the truth has not been able to be again found and recognized.

This same mode of operation has been followed by a contractor for the excavation of the Mindi Hills. In Culebra the blasting and light explosions suffice to shake a large mass and to make it dredgable, but the sandstone of the Mindi (Monkey Hill sandstone), though not of an exceptionally hard nature, requires quite a substantial blasting. The excavation by dry process of the canal in the Mindi was organized completely by dry process when the contractor, Jacob, signed his contract and had the whole plant turned over to him. He did not hesitate to take off the rails and cars and to attack by dredge with under-water mining. He followed the method with which I had experimented in 1885 in the first kilometers of the canal, and by which I excavated with economy the Monkey Hill rock under 7 feet of water. He prosecuted the excavation of the rock under water down to the bottom level, preferring that to open-air excavation.

I have described this method in my book of 1892, a copy of which I ordered to be sent from Paris to every one of the members of the Consulting Board who had not already this work in his possession. I have very few copies in my possession, but I think I could not do better than to offer them to the eminent engineers who are studying this grave question.

The adoption of the dredging method in two different places, with the aim of obtaining the most economical process and the most speedy one, and this with a ground which in both cases required mining, is a good example of the recognized superiority of this dredging process under conditions which generally would be considered as prohibiting the economic employment of under-water methods.

WHY DREDGING SOMETIMES FAILED ON THE ISTHMUS.

Whenever the dredging has been a failure on the Isthmus it has never been the fault of the dredge, but it was due to the incapacity of those in charge to dispose of the spoils after their extraction by the dredge and to find proper machinery for this purpose.

This question of disposing of the spoils is a question always more important than the excavation proper, and when they are loaded in scows a simple, ample, and assured way of dumping, such as the one I propose now, is the essential element of success.

If it can be said that the excavation by dredging is everywhere largely superior to the dry process in efficiency, in economy, in security for dredgable ground, is it sure to keep the same qualities with hard rock, which will be met below elevation 130?

To this question I answer that the cost of making the ground artificially dredgable, either by homogeneous mining such as I described in my book or by purely mechanical treatment such as is employed with great economy in the Suez Canal and elsewhere (15-ton Lobnitz hammers), will render the unit cost of the cubic yard of hard-rock work inferior to the excavation in the open air under the isthmian conditions.

It can be stated with certainty from practical experience, such as the records of the Suez Canal may show, that under the very propitious conditions in which the excavation will be made on the Isthmus, without currents and without variation of water level, it can be made at a cost much below $1 per cubic yard, including repairs and depreciation of machinery. It can be equally stated from the same Suez Canal records that their rock may be extracted and dumped, including repairs and amortization of machinery, at a cost inferior to 75 cents a cubic yard. As for the hard clay, even with the light blasting it requires the price ought to be kept below 30 cents a cubic yard with ordinary dredging, and much reduced with electrical appliances, even including 12 cents for the amortization of the locks ascending to Lake Gamboa. The excavation of hard clay may be brought still lower with the new dredging apparatus resulting from the combination of cutters and suction pumps, but this is an eventuality of the future, and, though already resting on large experiments in Canada, it is not sufficiently proven adaptable to the isthmian ground to base reasonable and conservative estimates, such as I give to-day.

THE CERTAIN WAY TO REDUCE EXPENSES BY DREDGING LIES IN THE ELECTRIC WORKING OF POWERFUL INSTRUMENTS.

But the other and very certain way to reduce the expenses will be obvious when we shall observe how perfectly a system of dredging works, such as will be organized along the summit level, is adapted to the use of electric distribution of power.

I have with this end in view prepared the way for the employment of electricity in the working of the dredges, and I had built in Holland, by Smulders, in 1895, an electric-driven dredge according to special plans which I drew, and which was, so far as I know, the first electric dredge ever employed in public works. The results I obtained on the river Esla, in Spain, have been eminently satisfactory, and convinced me that thereby the dredge could acquire new qualities, reducing the expenses and the risk of accidents by unforeseen obstacles met under water.

An unforeseen obstacle if met during the dredging causes a jerk on the chain, which tends to stop the engine or to break the chain; such a contingency in an electric dredge causes an increase of current, which, if exaggerated, simply melts a security lead.

LARGE DECREASE IN THE PRICE OF EXCAVATION AND TRANSPORTATION.

Such a distribution of power under electrical form will practically leave on board the dredge but an insignificant number of men, and one may readily understand the extraordinary economy of such a system of excavation producing 6,500 cubic yards in twenty-four hours with three shifts of 15 men, say with 45 men a day, even admitting the average abnormal price of $3 per man. The price of excavation proper will be reduced to $135 for 6,500 cubic yards, or about 2 cents a cubic yard for the labor.[a] This will be associated with a very reduced amount of expense for the repair of machinery, owing to the employment of electricity, and with no expense to speak of for the generation of power; that will be given by the falls of the Gamboa and Bohio lakes, which will easily furnish the 15,000 horsepower needed for the whole system.

The transportation would also be realized at a cost of perhaps 1 cent a cubic yard. The scows would have electric-driven screws and would take their power from a trolley line along the summit level and on the lake. One line would be for scows going to the dump and the other for scows returning; assistance of tugs would only be required near the dredges, near the locks, and near the dumping places.

I firmly believe that such a plant would reduce the price of excavation to a level difficult to believe.

From every point of view one must consider that the substitution of wet for dry excavation, if so understood, will create a veritable revolution in the prices and in the output of the work, owing to the great economy, efficiency, simplicity, and limitation of labor thus realized.

I consider that, outside of the great advantage of an early opening to navigation, this system ought to be adopted for all excavations below elevation 130, even if the sea-level canal should be constructed at once without any intermediary phase.

I need scarcely add that even admitting half the efficiency named for the dredge, the price would remain practically the same.

A DEPTH OF EXCAVATION 35 TO 50 FEET BELOW WATER LEVEL PERFECTLY ADVANTAGEOUS FOR DREDGES BUILT FOR THE PURPOSE.

I would have finished with the subject which ends the question of transformation if I did not desire to answer a statement which can be found in the remarks already alluded to and which precedes the reproduction of the letter to the President in the gray pamphlet, Panama Canal, Part IV. It is stated there that dredges can not work with advantage at such low depths as from

[a] This extraordinarily low price is not surprising if it is thought that Mr. John F. Wallace excavated ground near Colon with the old and relatively small French dredges at 7 cents per cubic yard.

35 to 50 feet. There is an evident misunderstanding in such a statement. It is just as easy to build dredges working to their best effect between 35 and 50 feet as it is to build others working to the best effect from 15 to 30 feet. It simply depends upon the length of the hull and of the ladder. All dredges, as a rule, are built to dredge between 15 and 30 feet, because it is the depth ordinarily required. Therefore, if to-morrow a work has to be executed at 50 feet, there will be no dredge prepared for that depth, and the dredge which will reach this depth will do it under disadvantageous conditions. But this is not at all a matter of principle, and nothing prevents us from making a dredge which will do admirable work between 35 and 50 feet. I repeat, it is simply a question of longer hull and longer ladder.

Fourth Part.

NEW PROSPECTS OPENED BY THE GREAT REDUCTION OF PRICE AND OF TIME OF THE WORKS OF EXCAVATION—THE STRAITS OF PANAMA.

The extraordinary decrease in the practical price of excavation, and the extraordinary increase in practical excavating power which result from the method above explained, allow us to enlarge to a singular extent our views of the interoceanic water junction.

The sea-level canal is a form of passage very much above the lock canal, but with its reduced dimensions in width and depth it remains a canal, where the large ships are partially deprived of their liberty. Even with the enlarged dimensions supposed to be reached—300 feet at the bottom and 35 feet depth—they will not have water enough to navigate freely or to steer easily, and therefore they can not take care of any currents above 2 knots an hour.

For this reason it has always been thought necessary to establish tidal locks near the Pacific. The presence of locks in the canal, even sea level, the relatively narrow and shallow channel offered to shipping forces us to concede that the sea-level canal, though very much superior to the lock canal, remains still very inferior to a free, wide, and deep passage, such as nature offers between the Black Sea and the Sea of Marmora—the Bosphorus. In fact, it is as far below such a passage as it is above the lock canal.

The ideal form of the water junction across Central America is not a canal—it is a bosphorus. The conception of the Straits of Panama, to which the waters of the two oceans will have free access, where ships will pass from sea to sea in four or five hours, with no limitation whatever, with no locks to pass through, has been hitherto relegated into the land of dreams on account of the expense, on account of the time required.

THE PROPOSED METHOD MAKES A REALITY OF WHAT WAS YESTERDAY A DREAM—THE STRAITS OF PANAMA—WHICH, IF BUILT BY METHODS HITHERTO KNOWN, WOULD REQUIRE THREE-QUARTERS OF A CENTURY AND $900,000,000, EXCLUSIVE OF INTEREST.

The new method I have here above developed, if considered with the full extent of its consequences, transforms this dream into a reality, which will necessitate about the same amount of money and the same amount of time as the tide-locked sea-level canal actually contemplated; that is to say, twenty-five years of time and $300,000,000 of money, including in the first item the period of construction of the high-level lock canal, but excluding from the second the cost of the appliances, locks, and dams which it will have been necessary to erect for the early opening of navigation, as well as the surplus cost of the excavations made during this first period.

To justify these views, we take for a basis the figures given for a tide-locked sea-level canal 150 feet wide and 35 feet deep, as exhibited in Part III of the gray pamphlets prepared for the Consulting Board (pp. 192–198).

Such a canal would require about 200,000,000 cubic yards, of which, in round figures, 50,000,000 are estimated there to be hard rock, 100,000,000 to be soft rock, and 50,000,000 to be earth. Its cost is estimated at $320,000,000 and the time of construction twenty-four years, the unit price of hard rock being $1.40, of soft rock 90 cents, and of earth 50 cents. These are the figures corresponding to the Panama sea-level tide-locked canal.

The figures corresponding to the Panama Straits would be much higher, except for the cost and time of construction, which remain about equal.

THE CURRENTS DUE TO TIDES AND FLOODS NOT TO EXCEED 3.3 KNOTS IN THE STRAITS OF PANAMA.

The tidal currents which are to develop at Panama have been calculated by a commission of the Academy of Sciences of France, and its report is filed in the records of May 31, 1887. For a canal such as was then projected, 72 feet at the bottom, they were found not to surpass a maximum of 2½ knots; but the maximum current would be a somewhat higher one—about 2.9 knots—with the enlarged dimensions I am contemplating.

The professional and scientific authority of this commission is above any suspicion. They verified their calculations by showing that their formulas gave practically, if applied to the Suez Canal, exact results measured actually on this canal, where, between the Bitter Lakes and the Red Sea, there are currents, due to the tides at Suez, which reach 3 feet 6 inches above and below the level of the Bitter Lakes, 16 miles distant.

A current of not more than 3 knots may be, therefore, confidently expected, to which will be added the flood currents, which on exceptional occasions will reach 0.3 knot in the enlarged prism of the canal, which would lead to expect a maximum current only on rare occasions of 3.3 knots. One can not object that it is impossible to risk the enormous interests of the commerce on the more or less certain calculations of the current. It can be observed that when the canal will be sea level the locks of Miraflores will still exist and will serve as tidal gates with a slight modification. By leaving them open one may measure the intensity of the current and interrupt navigation for that sole purpose one day. According to what will take place the formula will be verified and no risk will attend the destruction of the locks.

To dispose of such a current it is necessary to give ample room to the ships, not only laterally, but below their keel. Therefore I propose to give to the Straits of Panama a width of 500 feet at the bottom, a depth of 45 feet at Colon, where no variation of level will occur, and an increased depth in proportion to the length, so as to reach 55 feet at Panama below mean sea level, which will give 45 feet depth in the lowest spring tides all along the straits.

EXCAVATION REQUIRED FOR THE STRAITS OF PANAMA.

The Panama Straits so conceived will require an excavation of 600,000,000 cubic yards, an increase of volume over the 200,000,000 cubic yards necessary for the tide-locked sea-level canal of 400,000,000 cubic yards, which, if divided according to their nature on the basis of the proportions fixed on page 198 of the gray pamphlet, will give us 150,000,000 cubic yards of hard rock, 300,000,000 cubic yards of soft rock, and 150,000,000 cubic yards of earth.

UNIT PRICES AND TOTAL COST OF THE CONSTRUCTION OF THE STRAITS OF PANAMA.

The dredging and transporting of earth will be fixed at 15 cents, including the amortization of the Gamboa Lake locks for 2.5 cents and including the amortization of plant.

The cost of mining and of making dredgable the soft rock is extremely low, as it consists largely of hard clay, for which very light blasting will be required in front of the dredges. We shall admit 10 cents for that special work, and take 25 cents for the removal of soft rock under water.

The hard rock will be treated either by symmetrical blasting or by the Lobnitz hammers. The experience acquired at Suez and elsewhere during the development of the Lobnitz method allows us to fix at a maximum of 50 cents the price per cubic yard of hard-rock breaking operations under our conditions of work.

The total price will be, therefore, 65 cents a cubic yard. If these figures can be given with the perfect confidence that they are much above what may be obtained in practice, it must be remarked that they only apply to under-water excavation.

A large part of the total cube will have to be excavated above elevation 130 by dry methods, and therefore will be more costly. It must, however, be remarked, first, that an ordinary dredge can attack banks 15 feet above water, and that this limit can be brought to 30 feet by employing a chainless dredge of my invention, which I have built and which gave most satisfactory results. It must be remarked that even for the ground above direct attack of the dredge,

if it can not be excavated by floating instruments it can be transported by floating scows, and that, therefore, the cost of transporting and dumping, which means fully 50 per cent of the total cost of dry excavation (see report of February 1, 1905, by Mr. John F. Wallace), will be reduced to almost nothing.

It must be also remarked that the hard rock is exceptional on the high part of the cut, and that, therefore, only earth and soft rock may be expected above elevation 130.

For all the reasons above stated I think that the prices of dry excavation of earth above level 130, which are exhibited on page 198 of the gray pamphlet, can be safely reduced from 50 cents to 25 cents, and that of soft rock from 80 cents to 45 cents.

If we take the average between the two figures respectively corresponding to earth and soft rock above and below elevation 130, we find earth 20 cents, soft rock 35 cents. If we apply this average price to the cubes we have named we find:

Hard rock, 150,000,000, at 65 cents	$97,500,000
Soft rock, 300,000,000, at 35 cents	105,000,000
Earth, 150,000,000, at 20 cents	30,000,000
	232,500,000
If we add to this amount for harbor, dam, electric power, controlling works of small streams, etc	17,500,000
We arrive to a total of	250,000,000
Or, with 20 per cent for emergency	50,000,000
Which leads to the grand total of	300,000,000

THE PANAMA SEA-LEVEL TIDE-LOCKED NARROW CANAL, IF MADE BY DRY PROCESS, WILL TAKE AS MUCH MONEY AND TIME TO BUILD AS THE STRAITS OF PANAMA, IF LATTER IS MADE BY PROPOSED NEW METHOD.

If we compare this figure with that inscribed at page 198 of Part III of the gray pamphlet as the probable cost of the tide-locked narrow sea-level canal, we find the latter one superior by $21,779,776 to our figure.

After having shown that the realization of the Straits of Panama will practically cost an amount equal to that of the narrow sea-level canal, it remains to make an estimate of the time required.

We think that if the figures showing the powerful output of 16 or more large electric dredges working in the summit level are kept in mind, namely, 30,000,000 cubic yards a year, that the possibility of excavating 600,000,000 is thereby established to correspond to a period of twenty years, to which must be added four years for the preliminary stage of the opening of the canal. We think also that a variation in the supposed efficiency will be easily corrected by increasing the plant.

Any engineer who will think these figures are not perfectly reasonable, because he is accustomed to have in his head the figures corresponding to excavation by excavators on rails and transportation by trains and dumping by hand, must think that there is between a powerful electrically-driven plant working on water and an ordinary plant working on rails the same relation as for cost and as for power of transport as there is between the cost of transportation by ship and the cost of transportation by rail, and between the power of transportation of a ship and the power of transportation of a train.

He must, to do justice to these conceptions, imagine that a railroad man, accustomed to think that the cost of transportation under the most improved methods from the Pacific to the Atlantic by rail will be about $10 or $12, will be unable to understand how the same distance may be reached on sea for $3 or $4 with the proper steamers.

This is all the simple mystery of a method that carries with it such astounding results.

Conclusion.

THE HIGH-LEVEL LOCK CANAL FIRST—THE STRAITS OF PANAMA AFTERWARDS.

The general idea embodied in the project for the erection of a lock canal, to be later transformed to sea level, answers rigorously to the conditions which the President of the United States has outlined to the members of the International Board of Consulting Engineers as controlling the problem submitted to them.

The lock canal presented as corresponding to the first phase is the canal that can be opened with the utmost possible speed. The lock canal presented as corresponding to the first phase is also the canal that can be opened with the highest margin of safety. It is the canal which presents the lowest earth dam, annihilating, therefore, any risk whatever that could be opposed with justice to a higher earth dam. It is the canal that presents the lowest cut in the summit level, and, therefore, which reduces to the minimum the risk of finding a soft stratum necessitating large and long works to prevent a landslide, the very idea of which is terrifying in such a deep cut.

For these two reasons it may be said that it is not only the quickest but also the safest to build, and that it affords the required ample and permanent communication between the oceans in exactly the same manner as any lock canal with a lower summit level, except for the time of transit, which the President of the United States has declared to be secondary, if compared with any economy of time and any reduction of risk during the construction.

The President of the United States has also requested the Board to examine if, in case a multilock high-level canal should be adopted, it is possible later on to transform it to sea level.

The argument presented demonstrates the feasibility of such a transformation under conditions of theoretical and practical perfection. It conveys outside of this particular quality the other and very essential feature of leading to a method of excavation of great power and corresponding cheapness, resolving entirely the labor question and utilizing the natural forces of the Isthmus to an unprecedented extent. With the great reduction in the price of excavation this system allows us to anticipate, as a simple and reasonable end of the transformation, not only the sea-level canal with a tidal gate on the Pacific, but the real bosphorus, the real Straits of Panama, which can be crossed in five hours. To acquire this desired end it is necessary to have a canal 45 feet deep at lowest tide, 500 feet wide at the bottom, and 600 feet wide at the water line. The tidal currents would, in such a waterway, have no influence on the ships provided with abundant water under the keel and on their sides, and therefore provided with the necessary conditions to steer freely and to navigate with independence.

Such a project, which would be chimerical with the ordinary system of works, as it would lead to a surplus excavation of 400,000,000 cubic yards over that of the canal with 150 feet width and 35 feet depth, is in itself a perfectly reasonable and a comparatively easy task to do in a maximum of twenty-five years, at a total price equal to that which would result from the immediate sea-level excavation by a dry process of a narrow tide-locked sea-level canal. The schedule of time, which I think may be kept completely, would be, opening the 130-level canal in four years and excavating the rest of the waterway in twenty-one years.

The present plan presents, then, if compared with the immediate sea-level execution by dry process, the opening to navigation in four years instead of twenty, at least, and the possibility of completing in about the same space of time required for the sea-level construction and at a cost about equal, a cut of 600,000,000 cubic yards, instead of 200,000,000 necessary for the narrow sea-level canal, thus creating a real bosphorus—the Straits of Panama—which will afford to shipping the open and unhampered passage, without any lock, tidal or no tidal, in a wide and deep waterway 600 feet wide at the water surface and 45 feet deep at the lowest tide.

Such a programme, however tempting it is, was never formulated by anybody, because it would have required seventy-five years of time and $900,000,000 of money for its execution. It

has therefore been hitherto relegated into the land of dreams, but it becomes now a reality owing to the logical and scientific utilization of the conditions created by the establishment of a waterway across the massif central and of an interior sea by the Gamboa dam.

One may say that the Straits of Panama will be made by the temporary high-level lock canal. If this is true technically, it is true also financially. The earnings of the transit will certainly be more than $15,000,000 yearly average during the twenty years of the transformation; that is to say, will cover more than the yearly amount of the expenses of transportation.

Mr. Chairman and gentlemen of the Board, I have finished the exposé of the different solutions I desired to submit to you. I think I am justified in believing that they cover, as I said in my first words, all the requirements of the question, and that they satisfy all the enormous interests involved.

MEMORANDUM.

1. The project presented aims at the creation of a water communication between the ocean with the utmost possible speed and with the minimum of risk.

2. It fulfills these two conditions because it is, among all the projects known, the on presenting the lowest and narrowest earth dam and the least deep cut.

The excavation can be done in four years, if it is not thought impossible to reach now the same activity of work which the old company regularly obtained in the three last years of its existence.

The locks and dams can also be constructed within the same period on account of their entire independence of the works of excavation, as it has been established in the body of the remarks. The only thing which might prove a difficulty is the collection of sand along the beach at Panama or along the banks of the Chagres above Matachin (sand and gravel). In view of simplifying the work, it would be well to study the entire elimination of sand in the concrete, as has been done with entire success in France.

The constitution of a concrete made of 0.84 cubic meter of broken stone, mixed with 700 kilograms (1,550 lbs.) of Portland cement per cubic meter of concrete, will appear more costly at first glance, but might result cheaper in the end on account of the simplification it would afford in the operation. Another method would be to break the stone for concrete with two dimensions, the large ones with a maximum dimension of 2½ inches, the small ones with a maximum dimension of half an inch, and to eliminate the sand.

This delay of four years necessary for excavating a total cube of 60,000,000 yards, of which 20,000,000 only are to be extracted from the central cut, corresponds to the delay of eight years fixed by the Isthmian Canal Commission in their report of 1901 for the excavation of 43,000,000 cubic yards in the central cut, which was necessary, instead of 20,000,000, on account of the deeper central cut (minimum summit level 84 feet instead of 130). It corresponds also to a delay of more than twenty years fixed by the same Commission for the excavation of 103,000,000 cubic yards in the central cut, if a tide-locked sea-level canal is adopted immediately.

The determination of the delay of four years does not, therefore, result from any theoretical and hypothetic admission. It is based for the total cube on the same yearly output regularly obtained during three consecutive years by the old De Lesseps company, and for the cube in the central cut on the output admitted by the Isthmian Canal Commission. Everybody is at liberty to add according to his own idea a margin for the preparatory works. The Isthmian Canal Commission fixed two years for these preparatory works, but more than a year and a half has elapsed since the United States took possession of the canal, and the larger part of these works must be to-day made.

3. The only difference between two lock canals having a different number of locks (all other elements remaining equal) is that the time of transit is reduced by one hour and a half for every two locks suppressed. It may therefore be stated that the proposed canal will have the same carrying capacity and the same consumption of water as any lock canal with a lower

APPENDIX F.

ANNEX TO THE REMARKS OF MR. BUNAU-VARILLA BEFORE THE CONSULTING BOARD SEPTEMBER 18, 1905.

Longitudinal profile of the Panama route showing:

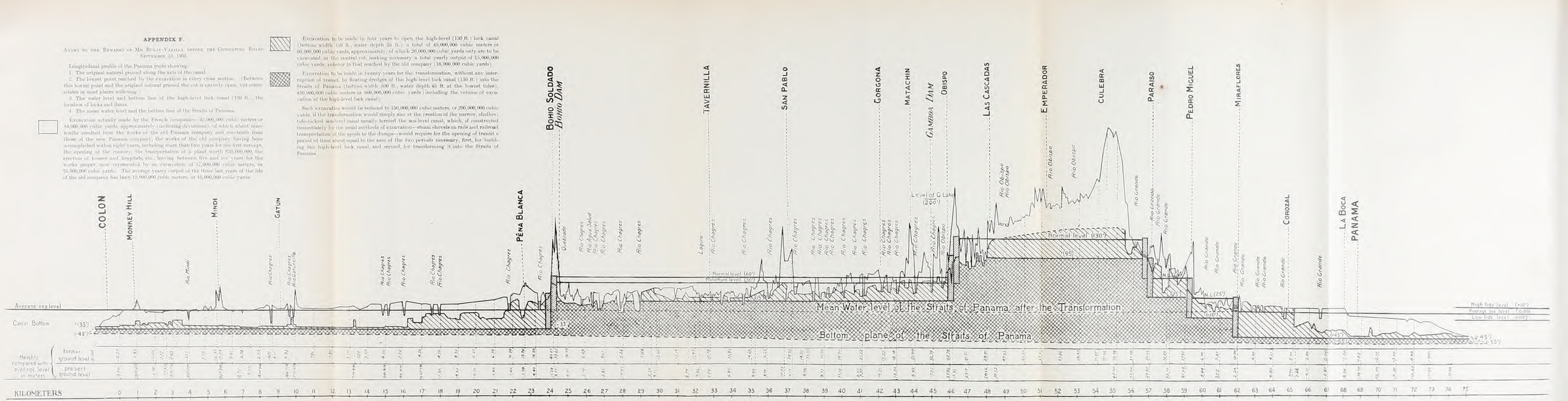
1. The original natural ground along the axis of the canal.
2. The lowest point reached by the excavation in every cross section. (Between this lowest point and the original natural ground the cut is entirely open, but necessitates in most places widening.)
3. The water level and bottom line of the high-level lock canal (130 ft.), the location of locks and dams.
4. The mean water level and the bottom line of the Straits of Panama.

Excavation actually made by the French companies—87,000,000 cubic meters or 84,000,000 cubic yards, approximately (including deviations), of which about nine-tenths resulted from the works of the old Panama company and one-tenth from those of the new Panama company, the works of the old company having been accomplished within eight years, including more than two years for the first surveys, the opening of the country, the transportation of a plant worth 850,000,000, the erection of houses and hospitals, etc., leaving between five and six years for the works proper, now represented by an excavation of 57,000,000 cubic meters, or 76,000,000 cubic yards. The average yearly output of the three last years of the life of the old company has been 12,000,000 cubic meters, or 16,000,000 cubic yards.

Excavation to be made in four years to open the high-level (130 ft.) lock canal (bottom width 150 ft., water depth 35 ft.), a total of 45,000,000 cubic meters or 60,000,000 cubic yards, approximately, of which 20,000,000 cubic yards only are to be excavated in the central cut, making necessary a total yearly output of 15,000,000 cubic yards, inferior in that reached by the old company (16,000,000 cubic yards).

Excavation to be made in twenty years for the transformation, without any interruption of transit, by floating dredges of the high-level lock canal (130 ft.) into the Straits of Panama (bottom width 500 ft., water depth 45 ft. at the lowest tides), 450,000,000 cubic meters or 600,000,000 cubic yards (including the volume of excavation of the high-level lock canal).

Such excavation would be reduced to 150,000,000 cubic meters, or 200,000,000 cubic yards, if the transformation would simply aim at the creation of the narrow, shallow, tide-locked sea-level canal usually termed the sea-level canal, which, if constructed immediately by the usual methods of excavation—steam shovels on rails and railroad transportation of the spoils to the dumps—would require for the opening of transit a period of time about equal to the sum of the two periods necessary, first, for building the high-level lock canal, and second, for transforming it into the Straits of Panama.



summit level. The only advantage obtained by the reduction of the number of locks, which is the reduction of time of transit, has to be purchased by more delay and more risk in execution, owing to deeper cuts or higher earth dams.

4. Outside of the first end aimed at by the creation of the high-level lock canal, the opening of interoceanic navigation, there is another and not less important end in view—to create the necessary conditions to prosecute the works of excavation down to sea level by floating dredges instead of by excavators working on rails.

5. The power of excavation of instruments working on water is about two to three times greater than what can be obtained from a plant working on rails.

The price of excavation, which is, roughly speaking, in inverse proportion to the power of execution, is consequently two to three times smaller with the dredging plant than with the dry process. The Isthmian Canal Commission has established plainly this fact by putting in the schedule of prices inserted in their report of 1901 that the removal of earth not handled by dredge would cost 45 cents per cubic yard, and that the removal of dredgable material would cost 20 cents. The proportion of 1 to 2.25 fixed by the Commission applies to all conditions of dredging, some of which may be more expensive on account of the necessity of dredging in a current or with a variable level of water or under complicated conditions of disposing of the spoils. With the ideal conditions of dredging, transporting, and disposing of the spoils that will be found in our case during the transformation, the proportion between the price of excavating in the wet and in the dry systems may be confidently put at 1 to 3—the ratio between the corresponding powers of excavation being 3 to 1 in the two systems.

6. The under-water rock excavation, this bugbear of ancient engineering, is no more a question of any gravity. Rock can be easily made dredgable by breaking it as a grocer formerly broke his sugar, but with a hammer of 15 to 30 tons or more instead of a hammer of half a pound. This system—the Lobnitz system—has been experimented with, always successfully, in all kinds of rocks; the harder the rock the heavier must be the hammer, but with a cheapness varying with the weight of the hammers. With 15-ton hammers the Suez company obtains the dredgability of rocks of a hardness which would correspond to the greater part of so-called hard rock in Panama at a very limited expense (25 cents per cu. yd.). It was nearly a failure at Suez twenty years ago with 4-ton hammers, and the price gradually decreased when the weight of hammers increased. With 12-ton hammers, much too light for hard rock, hard gneiss was hammered for $1.25 per cubic yard and mica gneiss for $2.27 at Phillipville. It reached at St. Nazaire $3.66, but under extremely unfavorable circumstances—with a small depth to excavate inside of a dock and with an inclined surface of the rock. With 25 or 30 ton hammers the very hardest rock will be broken for 75 cents to $1 at most, and if the energy is gratuitously delivered under electrical form, the price will be reduced by one-half, at least, for all kinds of rock, thus bringing the price of excavation by dredge of rock under water much below the price of open-air extraction.

7. The very low price of dredging and the very low price of rock breaking usually obtained will be still very much reduced at Panama on account of the marvelous facilities afforded by the constant level of the water, by the lack of any current, by the presence of a deep body of water (the Gamboa Lake) which will be united with the summit level by a double chain of locks during all the transformation, and where every loaded scow will unload itself by simply opening its bottom gates, without any fear of filling the lake, which can absorb many times the amount of excavation necessary for the sea-level canal; and last, but not least, by the gratuitous delivery of mechanical energy under electrical form to the dredges for excavating, to the scows for transporting, to the hammers for rock breaking. Said mechanical energy will be furnished by the fall of Gamboa and Bohio lakes in superfluous quantity.

There can be no reasonable objection raised against dumping into the lake on account of the possibility of filling it, or on account of the necessity of reserving its entire volume for the eventual sediments. The natural ground at the dam site is about 50 feet above the sea (15 m.). At elevation 132 the lake area will be 14.9 square miles or 3,857 hectares, at elevation 170 the lake

area will be 30.8 square miles or 7,963 hectares, at elevation 200 the lake area will be 43.3 square miles or 11,209 hectares. The total volume of such a lake is about 2,050 million cubic meters, of which 1,100 millions are devoted, between elevation 160 and elevation 200, to the storage for dry season and to the control of the floods, namely, half for each of these two parts the lake has to play. There will remain, therefore, below the lowest lake-water mark, 950 million cubic meters of dead water. After dumping the 450 million cubic meters (600 million cu. yds.) necessary for the Straits of Panama, more than half the space below the lowest lake-water mark will remain unused and filled with dead water. The sediments, as we have shown, can not be of any importance whatever. This has been demonstrated in the body of the remarks, and is also established by the eighteen years' experience of the Rio Grande Lake.

I have built across this small river, near Culebra, a dam 45 feet above its foundation and about 30 feet above the bed of the river. It corresponds on the Pacific side of the central massif to what will be the Gamboa dam on the Atlantic side, but on a very reduced scale. The lake formed eighteen years ago, and which is now to be used for providing Panama with water, has not been filled by sediments nor its surface reduced by them since the already remote date of its creation.

The Gamboa Lake will not be filled either by the dumps or by sediments high enough to ever reach the part where its water surface will have to oscillate. The dead part below will be half filled by the dumps, and that is all. It may be added that when the sea level will be reached the storage for feeding the summit in dry season will be no more necessary. The space between elevation 160 and 180 will no more be used for the storage, and therefore the surface oscillation will not go below 180 elevation, this being the inferior limit necessary for flood control; therefore the volume of dead water below the lowest lake-water mark will remain the same as before the works, and the space occupied by the 450 million cubic meters dumped will be substituted by the volume of 550 millions no more used for dry-season storage between elevation 160 and elevation 180. After the excavation of the Straits of Panama the volume of dead water will be greater than at the opening of the lock canal, all other conditions remaining equal.

8. The dredging from water, transportation on water, and dumping into water, which is a consequence of the first establishment of the high-level canal, furnishes the entire solution of the Panama problem, just as a similar dredging method, but of course with different arrangements, furnished at Suez forty years ago the solution of the Suez Canal construction, when the Viceroy of Egypt withdrew the corvee (compulsory labor of the fellahs), a thing which in the minds of the enemies of the Suez Canal was bound to doom the canal, but which really saved it, thanks to the necessary substitution of powerful dredging for the inefficient hand labor. Curiously enough, the enormous advantages of the dredging system proposed by Mr. Lavalley did not strike the scientific advisers of Mr. De Lesseps, but the new method was forced through by his superior genius in spite of the opposition shown, and the Suez Canal became a fact.

9. The dredging system above described allows to consider the hitherto impossible and otherwise inadmissible scheme of excavating within twenty years not only the narrow, shallow, tide-locked, sea-level canal (150 ft. wide and 35 ft. deep), but the Straits of Panama, free from any locks (500 ft. wide and 45 ft. deep at the lowest tides). This will necessitate three times as much excavating as the narrow, shallow, tide-locked, sea-level canal, but it can be made within the same period of time and for the same expense, owing to the prosecution of the digging by a system which, roughly speaking, is three times more powerful and three times more economical than the only one available for direct sea-level canal construction—the excavation and transportation on rails.

10. These works, as has been fully demonstrated in the remarks before the Board, and as had been already recognized by the Isthmian Canal Commission before in its commentary on my project, are entirely practicable and feasible without interfering at all with the interoceanic transit. During all the process of transformation the three essential elements of the canal will be completely respected—not an inch of the navigation channel, not a minute of the time of the locks, not a drop of the water necessary for feeding the summit level will be borrowed for the works of transformation.

11. The Straits of Panama, the unhampered, free, deep, and wide water junction, is the only form of passage which will give to the waterway not only its full economic but also its full military value. So long as a lock, tidal or no tidal, will remain which a cartridge of dynamite can cripple, the passage will be weak from a military point of view.

12. The creation of the Straits of Panama will be a direct consequence of the creation of the high-level lock canal. This first form of a canal makes possible what would otherwise be impossible. It will generate not only the technical means, but also the financial means. This great conception can be realized without any burden for the United States Treasury, because the average yearly cost of $15,000,000 during the twenty years' transformation will be furnished by the earnings of the lock canal. The Panama transit will be much larger than at Suez, and this latter canal has been earning more than $15,000,000 annually during many years.

13. My remarks before the Board of Consulting Engineers bearing on sixty-one different essential points of the Panama Canal problem fully explain the views based on twenty years' study of the great technical problem.

Without repeating here what I have already developed, I beg to give an emphatic warning against the illusions which might result from the theoretical output of powerful instruments of excavation working on rails. Indeed, the limitation to the output of the works did never come and will never come from the weakness of excavating instruments.

The difficulty is not to shovel earth or broken rock, and to lift it in the air; it begins at that moment and ends when the car which receives the spoils is unloaded at the dumps. The real difficulty is the transportation inside of the cut on a prodigiously complicated and extensive system of tracks; on tracks that will have to satisfy a traffic much larger than that of the great railroad stations; on tracks which can not be ballasted, because they have to be moved and shifted constantly to follow the progress of the excavation; on tracks that are naturally and obligatorily in bad order, washed by tropical rains and maintained by careless colored workmen. It is from this terrible state of affairs that comes the inevitable break, which paralyzes the whole machinery and reduces to an astonishing extent the output theoretically calculated.

The deeper the cut the greater will be the difficulties of moving along the cut the loaded and unloaded trains and the higher will be the number of these unavoidable derailments, which block whole lines of excavators and the recurrence of which disheartens the strongest wills and melts iron energies.

I have recently read that the great actual obstacle of the Panama works is the employment of toy cars and toy locomotives, left by the French, and which serve the new powerful American steam shovels. Not a farthing has been paid for the French plant; there was, therefore, no necessity of making use of it and nothing prevented ordering powerful 60-ton locomotives to replace the 30-ton French ones. If this has not been done, it is not for a reason of economy; it is because a heavy locomotive could not make one mile on a track laid inside of the cut without destroying it completely.

The remedy can not even be found in increasing the weight of the rails (60 lbs. per yd.). The colored men have little strength in the arms and such a rail as was used by the old French company is about all they can carry. As for the so-termed toy cars, they are steel dump cars holding 6 cubic meters, or about 10 tons. They have the same carrying power as the greater number of the freight cars used in England or on the European railroads. To increase their size and resistance in order to receive the masses of rock unloaded by the steam shovels is obviously desirable, but this increase will mean heavier duty for the tracks and therefore more derailments.

In fact, contrary to the current erroneous ideas, the excavation on rails has made no progress since the time of the old company, because it is principally a matter of transportation and because rails do not carry more nor better than formerly. Our French steam shovels had a working capacity of 1,250 cubic meters in ten hours, and they did more than that at the reception trials. Their average output, if my memory is correct, was 125 cubic meters during the rainy season (9 months), 225 during the dry season (3 months), which shows how little capital must be made of the experimental shoveling power during a trial, because the real output depends only on the transportation and very little on this shoveling power. This small efficiency, due to causes that

are still there and will be always there, has attracted on the old company the blind and unjust criticism of the ignorant. However, the truth gradually appears, and Mr. Stevens, chief engineer of the Panama Canal, has nobly declared before the Board of Consulting Engineers that the works made by the French deserved admiration.

The great advantage of the dredges is to suppress all difficulties of transportation; there is simply to open the bottom gates of the scows at the lake dump. A scow does not derail, it is independent, it is not exposed to accident, and if one happens it has no repercussion on another dredge or scow. The difficulty is really over when the scow is loaded; it begins when a car is loaded.

Contrary to dry excavating, the progress of which is limited by the weakness of the rail, dredging under water has made great progress since twenty years on account of the unlimited power of support of the water. No dredge having buckets of 1 cubic yard capacity was known twenty years ago. There was then no electric dredging, and cheap, under-water, mechanical rock breaking did not exist.

If my figures are too low for the construction of locks and dams in four years, after this period amply sufficient for excavation, the whole force of the excavation, becoming free, will be turned on these works and their completion greatly accelerated. Pessimism may suggest five, six, even eight years instead of four, but this can not go further; the plans proposed will always remain the ones necessitating the minimum of time.

Quite contrary are the estimates of time for excavation of the Culebra cut to sea level. If they are not based on what has been demonstrated by the experience of the old company; if they are founded on the slippery estimates of the excavating power of steam shovels, without taking into account the enormous reduction that the difficulty of transportation of the spoils will cause; if the term of execution of the sea-level canal is fixed at ten or twelve years, I wish to place myself emphatically on record and to state that such an estimate of time is wholly misleading; that twice as much is surely necessary, and that the acceptance of such a short term, based on an hypothesis which experience declares to be wrong, would be one of the greatest calamities which would confront the Panama question.

It will be like declaring a war with a large army on paper and a small one in the field; it will be like a campaign opened with excellent guns, but with crippled and disabled soldiers to handle them.

It will be the renewal of the history of the first period of the De Lesseps enterprise with all its bitter disillusions. The same fundamental error will have been committed—the calculation of the output of the works from the theoretical working capacity of the steam shovels, reduced in a proportion which is thought to give an ample margin of safety, when the margin corresponding to reality ought to be two to three times greater.

The justification of the first Panama company at the beginning was that no human anterior experience was available, and that the only way open was to plunge heroically into the unknown to extract the necessary truth. If this experience is neglected to-day, there will be no justification for such a far-reaching error.

P. Bunau-Varilla.

Washington, D. C., *October 30, 1905.*

SECOND MEMORANDUM.

PRICE OF DREDGING ON WATER AT THE ISTHMUS.

Among my remarks before the Board I explained that owing to the ideal conditions which will be found, during the transformation, for dredging from water, transporting on water, and dumping into water, owing to the employment of very powerful dredges and large scows, and also to the gratuitous employment of electricity, the labor per cubic yard excavated would be reduced to 2 cents for dredging and 1 cent for transporting and dumping, leaving nothing to pay besides save the cost of maintenance of the machinery.

Though I think the real price will not be far from 3 to 4 cents, I admitted as a concession to the current ideas a price of 15 cents per cubic yard for dredgable material in my estimates of the total cost of the excavation of the Straits of Panama, including 2.5 cents for the amortization of the locks, which leaves 12.5 cents for the removal of each cubic yard instead of 3 or 4.

However large is the margin admitted, I do not doubt that the price fixed may have been the object of criticism and thought to be too optimistic.

On this capital point I can furnish to the Board a very interesting statement. I met, on Friday, November 3 last, the former chief engineer of the Panama Canal, Mr. John F. Wallace, and spoke with him on the plans I entertained for the reduction of labor and expenses in the excavation of the Straits of Panama after the construction of the high-level lock canal.

Though Mr. Wallace, at the beginning of our conversation, expressed that the only point where he differed from me in my plan of transformation was on the question of prices, he unhesitatingly admitted during my justification of said prices that he had removed the ground at Colon with the old French steam dredges at a cost of 7 cents per cubic yard.

The conditions of dredging at Colon are similar to those which will be met during the transformation—there is no variation of level, no currents, and there is the possibility of dumping into the sea the spoils by opening the bottom gates of the scows, as will be done on the Gamboa Lake.

The most important figure resulting from the works of Mr. John F. Wallace entirely confirms my statement. The dredges of the old company have a volume of buckets half as great as what is usual now; the scows are two or three times smaller. The number of men being practically the same for a large or small dredge, for a large or small scow, one sees that by employing the type I recommend the prices would be lowered to 3.5 cents.

If one adds to this consideration that of the important economy which the elimination of the cost of power generation will give owing to the substitution of gratuitous electricity for costly steam, and the corresponding elimination of the greater part of time lost for repairs, it is easy to see that the figure per cubic yard will be reduced much below the 3-cent level.

I think this fact is extremely important for the information of the Board, and that it justifies me completely when I say that the admission of a price more than four times larger in my estimates is, to say the least, exceedingly conservative.

PRICE OF ROCK BREAKING.

Another item which may have attracted criticism is the price I have admitted for the cost of hard-rock breaking—50 cents per cubic yard.

It must be remembered that this corresponds to $1 for rock breaking without the use of gratuitous electricity. It must be remembered, also, that I admitted 25 per cent of hard rock in the canal. In fact, the quantity of really hard rock will be much smaller and will not be beyond 10 per cent of the whole mass. The proof of the scarcity of hard rock on the Isthmus is established by the difficulty of finding quarries for the stones necessary for concrete.

If there were 25 per cent of really hard rock in the total mass to be excavated, quarries would be found on the sidehills everywhere. It is the contrary; the sound hard rock is practically very rare, and quarries giving stones in perfect condition are so difficult to find that it became a question of serious import when the old company began to crush stones for its locks.

Nearly all the so-called hard rock, like that of the Bohio quarry, contains in large quantities soft elements very close to the clay. The only real hard rock of the Isthmus is the basalt or andesite. But even this hard rock—which exists in very limited quantity, not certainly more than 10 per cent—will be extremely favorable to handle by the Lobnitz method. This hard rock will present itself always divided in small masses instead of presenting itself in enormous compact masses as granite or gneiss.

The appearance of the isthmian rock on the surface of the earth scarcely precedes that of man. It was submitted to the fissuration which results from a sudden exposure to a much colder atmosphere. The gneiss or granite remained in compact masses on account of the extremely slow process of cooling.

Now, it is obvious that the hardness per square inch is not so much to be taken into consideration for the action of the Lobnitz hammers as the compact or divided state in which the mass presents itself. These hammers falling on rocks already subdivided, as the basalt, will crush easily the separate elements which they meet. When falling upon compact and large masses of granite the attack is more difficult.

For these two reasons—scarcity of really hard rock and the divided state in which such hard rock is found—I do not hesitate to think that the price of $1 for steam rock breaking, if applied to one-fourth of the total mass of the excavation of the Straits of Panama, is really absurdly exaggerated. It is so much more so if we think that 25-ton hammers will be employed instead of the 15-ton ones which give already so economic results. To say $1 per cubic yard for steam rock breaking means exactly as much as 50 cents for electric rock breaking.

I can say the very same thing of the price of 10 cents I admitted for the electric hammering of soft rock. It corresponds to 20 cents for steam hammering. The proportion admitted for the soft rock in the total excavation is 50 per cent. This enormous amount shows that the Culebra argillite is considered as soft rock. This will be destroyed and made dredgable for perhaps 5 or 6 cents instead of 20. The real soft rock would dispose of a price of 50 cents in the total sum fixed if we should eliminate the hard clay. This means twice the price obtained at Suez for the same quality and most probably for a harder quality than what is understood under the denomination of soft rock (outside of the clayish rock, the argillite).

The price of 10 cents for soft rock, like the price of 50 cents for hard rock and the price of 15 cents for the dredging, are considerably above what will result from practice.

STONE AND SAND FOR CONCRETE.

As I have already stated in my first memorandum, the collection of sand will present such difficulties as would justify its entire elimination from the concrete. The collection of hard stones will present also important difficulties. On account of the scarcity of really hard material on the Isthmus, on account of the presence in nearly all the rocks of elements confining to clay, the collection of stones can not rest on the opening of large quarries systematically worked in view of obtaining a high-grade material.

It is very dangerons to rely, for the collection of stones and for the separation of good from bad ones, on the wisdom of the laborer; it will cost much money, it will employ a great number of men (a capital defect, the labor question being one of the most important factors to take into account for any reliable plan of operation), and it will never give the stones of the required quality and homogeneity.

I propose to eliminate entirely the question of stones and sand for concrete from the isthmian operations. I propose to bring these two elements into the Isthmus from North America or from the Antilles with a regular line of freight steamers, as will be done for the Portland cement. This decision will entirely liberate the isthmian labor from the complicated and confused question of the collecting of the proper stones, of breaking them, and of transporting them. It will leave for the works proper, excavation and building of locks and dams, the several thousands of workmen which would be employed for a work which can be infinitely better and cheaper made in the Temperate Zone.

The price of transportation by sea and of unloading at Colon, even if it reaches $4 per cubic yard, would not be superior to the material economy that will result from obtaining the material where labor is ample and efficient, and the quality of the material perfect. The freights for great masses regularly shipped are very low; and the enormous improvement made for unloading ore from ship to car by the Brown machinery, at Cleveland and in other cities of the Great Lakes, solves admirably the question of price and labor in the harbor of Colon. The transportation by train to the different locations of the locks and dams is equally easy with the heavy freight locomotives of more than 100 tons now in use on the American rails.

Without knowing the exact dimensions which will be selected by the Board of Consulting Engineers for the locks one may admit as a first approximation that the calculations may be based

on 500,000 cubic yards of concrete; that is to say, on about less than 750,000 tons of stone, sand, and cement for each twin lock of 35 feet fall. As there are eight twin locks in the plans I propose, the total mass to be transported within three years would be 6,000,000 tons, or 2,000,000 tons per year, or 7,000 tons per each of the 300 working days. This would lead to the formation at Colon of seven trains of 1,000 tons daily, a figure which is perfectly admissible for the section of the road situated in the valley of the Chagres. Trains would have left half of their load when leaving the easy gradients of the Chagres Valley, and the same engines could easily pull the remaining cars to the other side of the Isthmus.

Any man familiar with the magnificent results obtained on the Great Lakes for handling on ship, from ship to car, and on cars, large masses of material will state that these figures have nothing abnormal. By this method the three elements of the masonry of the locks would come to their destination without having borrowed practically any element from the precious and rare isthmian labor, which must be jealously kept for the isthmian operations proper.

Of course, to this amount has to be added the mass necessary for the Gamboa dam, but it will play a relatively minor part compared to what is necessary for the bulk of the eight large twin locks of the canal.

TIME OF CONSTRUCTION OF THE LOCKS.

The question of construction of locks is thereby reduced to the excavation of their sites and the depositing of concrete afterwards. To make the concrete simply consists in digging into deposits of stones, of sand, and of cement, loading light hand cars (two-thirds cu. yd. capacity), and in dumping them with the necessary quantity of water into tubes, from the other end of which the formed concrete falls in its place.

Being given the extreme simplicity of these operations and the large extension of the sites of the locks, it is extremely conservative to suppose that at every lock, say on each of the 16 locks (or 8 twin locks), a mass of concrete of 400 cubic yards may be deposited daily without any difficulty by a force of 200 men. This would make 800 cubic yards per each twin lock with 400 men, or 240,000 cubic yards per year. The depositing of the concrete would be then made within a little more than two years with a force of about 3,200 men.

It is easy, therefore, to see that under such a plan the realization of the locks within four years can be accomplished. If we devote two years for the excavation of the sites of the locks, and if the depositing of the concrete is started at the heads so as to finish with the heads within half a year, the erection of the gates will have one and a half years in which to be completed, which can be very easily done if the gates come from the States divided into large pieces of 10 tons or more, necessitating as little riveting as possible on the Isthmus.

Of course, in operating the canal the gates must be handled both by hand and by hydraulic or electric machinery. It does not enter in my four years' programme to have installed but the hand machinery. The more perfect machinery is not necessary at the beginning and will be erected later. The only difference between the time for the Bohio locks and the others is that their sites will be occupied one year by the deviated Chagres; therefore they must be done in three years instead of four, which I think perfectly practicable.

MARGINS OF SAFETY GIVING FULL GUARANTY THAT THE OPENING OF TRAFFIC WITHIN FOUR YEARS CAN BE SURELY ACCOMPLISHED.

As the President of the United States expressed it so justly to the Board of Consulting Engineers, the moment when the first ship will pass from ocean to ocean can not come too soon; this will be the day of the victory over nature. Now, it matters very little whether on that day the works are completely finished or not, as the traffic of 6 million tons that will pass during the first years does not necessitate the ample dispositions provided for. This traffic will correspond to an average passage in each direction of one ship every twelve hours. For such a small traffic the canal may be opened with a bottom width of 100 feet instead of 150. For such a small traffic the canal may be opened with one lock instead of two, if the upper head of the other one is

finished with its gate to prevent the water from entering the lock, and if the lower head is protected by a cofferdam.

Now, I have shown that the excavation can be made within four years without even reaching the yearly output obtained by the old company, which, in its last year (1888) it must be remembered, had also two or three thousand men occupied for the locks outside of those devoted to excavation proper. I have shown that the locks and dams can be completed within the same period of four years without any exceptional effort, and without admitting but very reasonable figures, very inferior to what I have personally obtained in works consisting in the preparation of large masses of concrete.

However, if certain events should obstruct the regular evolution of what is based on figures so perfectly reasonable and so perfectly moderate; if the lack of labor, for example, should partly paralyze the works—though labor necessary, in my plans, is not greater than what the old company had gathered from the West Indies—it would be still possible to obtain the passage for the largest ships actually afloat within four years by reducing one-third the width of the cuts, which would remain about equal to that of the great canals of the world, and by limiting the effort to the construction of locks to one lock and of the vital parts of the second one of each twin lock.

The entire completion of the high-level canal with its normal dimensions would then remain a question of one year, or two at most, afterwards, and at the same time the strategical position would be conquered which guarantees the construction in twenty years, without any perturbation for the traffic, of the Straits of Panama, the only complete solution of the problem for the economic and military necessities the highway has to meet; the great waterway free from any tidal lock, 500 feet wide at the bottom level, 45 feet deep at the lowest tides, when the sea-level canal will be hampered with tidal locks and the channel restricted to 150 feet at the bottom and to a depth of 35 feet.

P. Bunau-Varilla.

Washington, D. C., *November 6, 1905.*

Appendix G.

STATEMENT OF MR. LINDON W. BATES BEFORE THE BOARD SEPTEMBER 19, 1905, AND DATA SUBMITTED SUBSEQUENTLY.

111 Broadway, New York, *October 23, 1905.*

Dear Sir: The undersigned has the honor to respond to the attached letter of October 2, received from Colon, in New York, October 12. He has complied with the request therein contained, in—

First. Some incidental corrections in the text of the hearing of September 18.

Second. As Appendix 1, a brief minute re lockage, supply, and capacity of projects A, B, and B′, which has been asked for.

Third. As Appendix 2, a summary of basic quantities and unit prices for the execution of the principal works of projects A, B, and B′ supplementary to table on page 163 of The Panama Canal System and Projects.

The writer begs to state that in view of possible future contract relations to the Panama Canal on the part of his associates and himself he has, as set forth on page 161, figured a system of structural quantities and unit prices on the basis of a practical bid and its execution. These unit prices are naturally applicable to three projects only, and to them under his own proposed means and methods of execution alone.

As requested, the copy of the report of the hearing accompanying your letter is returned, and three complete sets of revised text and appendixes are herewith transmitted for convenience.

Very respectfully,

Lindon W. Bates.

Capt. John C. Oakes, U. S. Army,
Secretary Board of Consulting Engineers,
Isthmian Canal Commission, Washington, D. C.

Board of Consulting Engineers,
Isthmian Canal Commission,
S. S. Havana, October 2, 1905.

Sir: I have the honor to inclose herewith one copy of the report of your hearing before the Board of Consulting Engineers, at Washington, D. C., September 19.

Owing to the rapidity with which the questions and answers were made it was impossible for the stenographer to obtain a perfectly correct record. It is the desire of the Board of Consulting Engineers that you should read this record and make any corrections of statement and fill in any statements made which have been omitted.

The following resolution was adopted at a meeting of the Board on September 30:

Whereas Mr. Bates in his pamphlet has discussed the details of various estimates prepared by other authorities, but gives for his own projects only lump sums: Therefore,

Resolved, That in order to permit a proper comparison of Mr. Bates's projects to be made with other projects, he be requested to append to his oral discussion answers to the following questions:

"1. What are the quantities of materials in the main component parts of your projects which formed the basis of your estimate?

"2. What are the unit prices to be applied to such quantities to make the lump sum estimates contained in your pamphlet?"

Hoping to receive an early reply and return of the inclosed papers, I remain,
Very respectfully, yours,

JOHN C. OAKES,
Captain, General Staff, Secretary.

Mr. LINDON W. BATES,
111 Broadway, New York, N. Y.

Mr. Chairman and gentlemen, at the very outset of this hearing your indulgence for a personal reference is invoked to remove a somewhat natural inference that the speaker has of his own volition proffered suggestions or advice where it was not his concern so to do. On his return from Europe last winter his opinions were sought. One among others was formulated in the following words:

SEA OR SUMMIT LEVEL.

Determine level of central section and disposition of Chagres waters.

This is the momentous and fundamental problem. Its solution should be confided to the best proved engineering talent in the United States, and this judgment should be confirmed by a small board of experts drawn from the best engineering and contracting minds in the world. Their final report should give due weight to the financial question.

The President should retain the veto and remanding power in this decision.

The cost and success of the enterprise is supremely concerned with the determination of the central level. The French Comité Technique, with its international advisers, and the various American commissions have evolved four schemes of treatment known as the 90-foot-level project, the 60-foot-level project, the 30-foot-level project, and the sea-level project.

The studies and observations of the writer have led him to a new solution which appears sufficiently superior, technically and financially, to merit presentation.

The speaker in his ten years in other continents had learned that science was international and that no land or people had a monopoly of experience or common sense or the engineering brain.

This board is constituted; a proponent is before you.

It has come to pass that of many called you are chosen, and just as truly he accepted an imposed duty as a simple citizen to make the short exposition which was submitted in March last, with the especial and accepted reserve that in a due time a more complete presentation would be prepared than had been practicable under the pressure of those first few weeks.

What you have before you—this text, these plates and studies, reliefs and perspectives—are what have been wrought in a clear purpose to do honor to my inspirer, and aid all possible the rightness and perfection of your decision.

This presentation was meant to be and is practically complete.

You have been informed that it was novel and interesting, but lacked detail and data. New and interesting—yes; so once was the railroad, the telegraph, the sewing machine, and the steamship. These the world has already accepted.

This is neither the country where nor the age when new ideas, if they be true, are passed lightly over or crushed permanently to earth. Lacking study, detail, and data—no. To a practical analysis nothing pertinent to a decision is wanting, and challenging its disproof the speaker would like a bill of particulars.

But that the record may be complete the situation is summarized, that from the hour the first submission was made, March 5 last, not one step has been taken by those charged with isthmian details, despite the President's formal injunction when this Board was constituted and chartered, to make an official examination of certain localities where certain data would surely be interesting although not vital to the deliberations of this Board upon mine or other plans.

With some prevision the writer supplemented his own observations, but he requests that this correspondence be made part of the record, and the fact registered likewise that ample time elapsed between the President's order and September 1 to get that data, which you will see for yourselves if you are so minded.

CORRESPONDENCE RE DATA FOR PLANS FOR PANAMA CANAL TO ACCOMPANY LETTER OF JULY 8 TO GENERAL HAINS.

JUNE 24, 1905.

SIR: I beg to confirm that it is my desire and purpose to submit to the special Advisory Board of Engineers appointed for considering plans for the Panama Canal the fullest and completest presentation practicable of the projects for which I am responsible.

To secure this completeness it is desirable to have the data acquired up to this time, and particularly what have been obtained during the past fifteen months. I write, therefore, to request your grant of permission that these data be made available to me.

Doubtless new and important examinations are now also being conducted to anticipate the requirements of such a board, especially at Limon Bay, about Mindi, in the vicinity of Panama, in Panama Bay, and in the contouring of the valleys of the Chagres and the Rio Grande rivers.

It is my understanding that this is a matter under your care by direction of the President. Therefore I have ventured to bring this subject to your attention and to hope that this request may be granted as fully as consistent with the public service.

I have the honor to be, with great respect,

The honorable the SECRETARY OF WAR,
Washington, D. C.

JUNE 27, 1905.

SIR: By direction of the Secretary of War I have the honor to acknowledge receipt of your letter of June 24, requesting that all data which have been obtained during the past fifteen months be furnished you in order that you may be able to submit to the Board of Consulting Engineers a complete presentation of projects for the construction of the canal, for which you are responsible.

In reply you are respectfully informed that your communication has been referred to the Engineering Committee for consideration.

Very respectfully, W. LEON PEPPERMAN, *Assistant Chief.*

Mr. LINDON W. BATES,
111 Broadway, New York, N. Y.

JUNE 30, 1905.

SIR: I have the honor to acknowledge your letter of advice that by direction of the Secretary of War my letter of June 24 has been referred for consideration to the Engineering Committee, and to state that I hold myself ready to prepare all my proposed plans in such detailed form, with maps, surveys, and other documents sufficient to enable the Engineering Committee, the Commission, and the Board of Consulting Engineers to consider them in the most complete printed form and embodying the relations of these projects to the final official data, which I trust will be obtained and accorded in due season.

Very respectfully,

W. LEON PEPPERMAN, Esq.,
Assistant Chief, Office of Administration,
Isthmian Canal Commission, Washington, D. C.

JULY 3, 1905.

SIR: I have the honor to acknowledge the receipt of your letter of June 30, stating that you hold yourself ready to prepare all your proposed plans in such detailed form, with maps, surveys, and other documents, sufficient to enable the Engineering Committee, the Commission, and Board of Consulting Engineers to consider them in the most complete printed form and embodying the relations of these projects to the final official data.

In reply, you are respectfully advised that this communication has been referred to the Engineering Committee for consideration.

Very respectfully, W. LEON PEPPERMAN, *Assistant Chief.*

Mr. LINDON W. BATES,
111 Broadway, New York, N. Y.

ISTHMIAN CANAL COMMISSION,
Washington, D. C., July 7, 1905.

SIR: Your letter of the 24th ultimo to the honorable Secretary of War has been referred to the Engineering Committee of the Isthmian Canal Commission. The Committee has considered your request for data bearing upon plans for the Panama Canal and begs to inform you that if you will visit the rooms of the Commission, in the Mills Building in this city, all the data now in hand will be placed at your disposal for full examination, and if any data you desire are not found in the files of this office the Committee will procure it if deemed practicable.

Very respectfully,

MORDECAI T. ENDICOTT,
Vice-Chairman Engineering Committee.

Mr. LINDON W. BATES,
111 Broadway, New York, N. Y.

JULY 8, 1905.

DEAR SIR: I have the honor to acknowledge your esteemed favor advising me that doubtless there will be authorized an examination of the data now in Washington and the results of new investigations at Mindi, Chagres, and Panama.

I venture at this juncture to acquaint you with the exchange of letters which recently transpired and to say that the Secretary was addressed in accordance with the understanding that such should be the course.

I beg to express my great appreciation of your thoughtful courtesy in writing me and to say that, now word regarding the Committee's favorable action on the reference from the Secretary is received, I will proceed to carry out my part.

Yours, very respectfully, ——— ———.

Gen. PETER C. HAINS,
Office of Isthmian Canal Commission, Panama, C. A.

Five inclosures:
Copy of letter to Secretary of War June 24.
Copy of letter from Office of Administration June 27.
Copy of letter to Office of Administration June 30.
Copy of letter from Office of Administration July 3.
Copy of letter from Engineering Committee July 7.

JULY 8, 1905.

SIR: I have the honor to acknowledge your letter of advice that the Engineering Committee of the Isthmian Canal Commission has favorably considered the reference made to it by the honorable the Secretary of War of my letter to him of June 24, 1905, respecting data bearing upon plans for the Panama Canal.

In accordance with the opportunity thus afforded, I will visit the rooms of the Commission in Washington for full examination of the available data.

The special official data which I am interested to incorporate in the final presentation of the projects for which I am responsible are generally as follows:

1. Verification of position of the 6, 7, and 7½ fathom contours opposite Limon and Panama bays.

My data are from British Admiralty, United States Hydrographic, and French Canal charts, but I have understood that later surveys have been made.

2. Profile, classification, and sections along the canal locations indicated on the submitted plans, including the reception and naval basins at Mindi and Panama.

3. The correct areas of the Pequeni and Chagres watersheds, above Alhajuela. This has doubtless been ascertained by Mr. Boyd Ehle's party.

4. Contours for determining the volume of the—
   (*a*) Alhajuela basin.
   (*b*) Gamboa basin.
   (*c*) Caño basin.

The first two (*a* and *b*) are probably available, the Caño basin contours may not be on record.

5. Contours for determining area of—
   (*a*) Lake Chagres at 20 feet, 22.5 feet, 25 feet, and 27.5 feet.
   (*b*) Lake Panama at 20 feet, 22.5 feet, 25 feet, and 27.5 feet.
   (*c*) Lake Bohio at 52.5 feet, 55 feet, 57.5 feet, and 60 feet.

Those for Lake Bohio are available in Washington, those for the others have not been fully ascertained except near the canal line.

6. Contours of Obispo basin.

These are available in Washington.

7. Areas of watershed of Chagres below Bohio and above Chagres dike.

This is given as about 500 square miles, but this figure might be advisedly verified, as there appears to be no complete record of the run-off of the Chagres and its tributaries below Bohio, and the correct area would afford a fair method of estimating, using the coefficients established where the areas and run-offs are both known.

8. Topography and borings on the alternative locations of the—
   (*a*) Chagres River dikes.
   (*b*) Mindi dike.
   (*c*) La Boca dike.
   (*d*) Mindi lock.
   (*e*) Panama lock.
   (*f*) By-pass at Pedro Miguel lock (project B).
9. Data for the classification and estimate of quantities for projects A and B.
10. Data regarding the filling and other work required to raise the grade of the Panama Railway above the lake level.

I beg to express my appreciation of the considerate action of the Committee, and trust that what is not found in the file it will be possible to secure sufficient at least for practical purposes.

Very respectfully,

——— ———.

Rear-Admiral MORDECAI T. ENDICOTT,
Vice-Chairman, Engineering Committee,
Isthmian Canal Commission, Washington, D. C.

There is just one thing open: Which of a dozen sites is the best for the dam which closes the old lower channel of the Rio Chagres? This site for a Morison type of dam can be picked out in a fortnight's work, if only there exists the official will to do it.

Therefore the projects of the speaker are not to be pigeonholed because some one has said to the Chairman of the Commission that it would take a year to get the information which it was merely remarked was interesting, but, see you, never stated was in any degree vital.

In the past six months, although thousands of copies of the first monograph (as there will be of this last) have been sent in this country and the world over to engineers, technical journals, ship and navy men, bankers, diplomats, Congressmen, and Senators, etc., there is yet to come a single serious attempt at criticism. There has been and there can be no successful controverting of the correctness of the principles on which the projects are based; there can only be differences of detail as to sites and structures, wherein there is room for infinite variety and abundant field for the specialist.

Before reverting to any explanations the speaker begs to state that he apprehends that the absence of any comparative analysis of the 130-foot project from his discussion may be remarked.

If he should have formally incorporated it he utterly misjudges the temper, the purpose, and the aspiration of the people of America; of the reliance of the substantial honored Motherland, of the Fatherland too, both with a greater preponderance of ships than we Americans like to see—misjudges also the real ideal of the most precious nation, artistic France, and the temperate and tenacious wisdom of the water-schooled men of Holland. He has not believed that anyone wanted a high-level canal, although his study of such possibilities has been made, which is here briefly contributed to the record of this hearing:

NEW MATTER—PROJECT B″.

Levels.—33.5, 138.5, 26.5.

Locks.—Mindi, Gatun, Bohio, Santa Cruz, Pedro Miguel, and Sosa; total, 8.

Lake-making dams.—Mindi, Chagres, Gatun, Bohio, Santa Cruz, La Boca.

Lakes.—Chagres—Mindi to Gatun; Gatun—Gatun to Bohio; Bohio—Bohio to Santa Cruz; Obispo—Santa Cruz to Pequeni Junction; Panama—Pedro Miguel to Sosa-Ancon.

Regulating dams.—Above Alhajuela, Caño, Santa Cruz by-pass, Pedro Miguel by-pass, Bohio, Gatun, and Mindi barrages.

Premise.—To reduce the volume of the central pass pertaining either to project A, B, or B′, a higher summit level must be created.

An examination for possible dam sites shows several points between San Pablo and Obispo which may be considered, but the best is just below the mouth of the Rio Obispo.

The Gamboa dam site, less than half a mile away, makes it all but certain that a good rock foundation line will be found at about sea level, and just as good hill abutments exist on either side of the Chagres at Santa Cruz and El Hato as at Gamboa.

SANTA CRUZ DAM AND BY-PASS.

This dam, but 2,000 feet long, may be of the solid type or of the under-sluice Assuan design.

The Santa Cruz by-pass would be solidly closed in the case of adopting the latter and not used. It could be employed with the main dam of the solid form and provided with an under-sluice regulating barrage. The main dam will enjoy the advantages of the net-head system.

SANTA CRUZ LAKE.

The lake by this barrier would extend to kilometer 46 along the canal and up the Rio Obispo to the westward and nearly to the junction of the Pequeni and Chagres above Alhajuela.

DAM ABOVE ALHAJUELA.

The Assuan under-sluice dam should be built at a suitable site below the junction so as to incorporate for flood regulation the empty basin principle.

SANTA CRUZ LOCK.

Santa Cruz Hill affords a good location for one or several twin locks, without any material departure from the old alignment, and the change involves but little excavation on account of the lakes.

One lock will raise the summit level to 138.5 feet and vastly reduce the quantities of the divide cut, as shown on the profile herewith.

CHAGRES FLOW AND REGULATION.

Precisely the same principles as are set forth in the main exposition of project A, B, and B′ will govern the river, and its flow will likewise be sent to both oceans.

ALTERNATIVES.

Although the French condemned the San Pablo location for a high-head dam, nevertheless, by using the net-head system and a Morison type of design, it is feasible to plan still another dam, lock, and by-pass above San Pablo and by means of the Santa Cruz dam raise the summit level to 173.5 feet above the sea. This would lead them to a ten-lock canal and leave very little excavation in the Emperador-Culebra section summit, except on the upper terraces.

If a multilock canal be admitted these dispositions create the best conditions for the service of navigation and the regulation of the river.

FUTURE ELIMINATION OF LEVELS.

The French 130-foot high-level multiple-lock scheme proposed a dam at Gamboa and locks from the upper canal level into the lake above Gamboa for the disposition of spoil from Culebra. By a dam at Santa Cruz these locks are eliminated and material may be disposed in the lake or behind débris dams without their intervention. Such spoil locks are obviously superfluous.

The high-level scheme has no monopoly of the academic possibility of eliminating levels without interruption of navigation, as any level in any plan may be eliminated if there be no regard for cost and time.

But submerged-rock excavation, where blasting is requisite, costs, according to all past experience, far more than the excavation of such material in the dry or where it may be shattered in situ without the use of under-water drilling, loading, and blasting.

The unit prices universally current for submerged-rock excavation are from five to ten times those for handling rock where it can be readily gotten at.

The prices reflect world-wide experience and can not be ignored or glossed over by specious claims of dredge performance which have not been and will not be realized until some new invention has proved itself able to surmount this dominating difficulty.

For example, the sea-level cutting involves 310,000,000 cubic yards. The 130-foot, high-level plan will have dug less than one-third of this colossal mass, leaving over 200,000,000 cubic yards, of which half is rock requiring blasting and much of the rest so refractory as to gravely reduce shovel and dredge outputs. A certain proportion must be submerged-rock excavation.

Reckoning an average covering price for ordinary dry and dredging earthwork, dry-rock removal, and the inevitably large excavation of submerged-rock and refractory material, it is safe to say that the unit price will range higher than the $1.15 allowed by the Commission of 1901 for Culebra material. This modest rate works out $230,000,000, exclusive of interest, which, if the expense be spread over twenty years at 2 per cent will amount to $46,000,000.

The transformation of any high-level canal to a lower level will be an expensive and time-consuming operation.

It will be wise and prudent to get the Emperador and Culebra slopes and terraces into a state of suspended animation once and for all and then let them severely alone. It is infinitely better to determine on a definite plan, forego ill-based, illusory, and avowedly temporary expedients, and build as finally, rapidly, and economically as possible the canal—best politically, financially, and technically.

Project B′, 30 feet lower, has less excavation than the high-level canal at 130 feet, advocated by those who would substitute a makeshift for the registered ideal of America.

PROJECTS A, B, AND B′.

If the gentlemen will turn to the plate book they will see that Plate IV shows, in black, the comparative excavation of the various projects on the central line and is fully set forth in the text. Such an exhibit is more to the detriment of the projects for which I am responsible than it is to those with which it is compared. I have meant, in preparing these plans, simply to make this presentation so complete that nothing would really and actually depend upon what might be said at so brief a hearing; and I would point out on Plate V—it is the site of the Gamboa dam—the relation between a very high dam at Gamboa and one based on the under-sluice principle. To the left of the triangular basin, marked the Obispo basin, you will see the little villages of Santa Cruz and El Hato, which form the subject of the tentative study to which I have just referred. On the profile you will see the difference between the crest of the Assuan dam, for example, and the 200-foot dam.

Plate VIII is an analysis of the effect of the various projects upon the Panama Railway. It is very evident that any dam placed at Gatun which floods the basin to a level higher than +33 would require the intervention of a ferry system or a long detour, which is shown in the unsurveyed country up the Gatuncillo.

The lower plate shows the effect on the Panama Railway during the period of construction of project A. There is a certain moderate amount of grade raising through the swamp between Mindi and Bohio.

Plate IX is one on which I have incorporated the condensed records of the hydrography of the Isthmus. At the top of the page you will see graphically displayed the ratio between the gauging methods employed by the New Panama Canal Company and those of the United States Hydrographer. You will see that at low stages the results run rather close together, but at the high stages there are very serious differences, all of which are set forth in the text—that is, the figures merely show graphically what is shown in the pamphlet.

The dial has incorporated the régime of the Chagres River during the period of observations. By following any one of the curves marking the allowed discharge which may go through the sluice of the Gamboa and Alhajuela, you will see its relation to the floods. For instance, following the line of 44,000 cubic feet you will see (p. 42) that there is no record of a single flood (as shown by the dial 1893–1900) which would have touched the 44,000 mark. By taking, for

instance, 12,000 feet you can see exactly how many floods would be affected and how it is supremely easy to regulate the currents of the Chagres by allowing a stated amount to go through.

Upon the central plate is shown the five serious floods that have transpired of which there are records. The lower section shows the yearly, monthly, and seasonal means of the discharge of the river at the various ruling points. The lower one is necessarily made up as a deduction from the first three, but shows the increased amount of water which is available for lockage purposes.

On Plate X I have shown, along the course of the river, the sections of dams on the Morison principle; also dams with net heads and their relation to dams on the same principle with high heads. A similar diagram might have been made which would have displayed the great differences of volumes by the sections taken in a direction exactly opposite to that which has been used.

I think that all of these plates make it sufficiently clear to all of the gentlemen here, and that detailed explanations are not at all necessary.

On Plate XI I have incorporated sketch diagrams of the structure and dams at various ruling points, which have also been shown in the relief models made for the convenience of the Board. I would particularly point out that when a higher level is made between Mindi and Bohio the Gatun cut-off may be used and so diminish the distances about a mile and two-tenths nautical.

In the lower right-hand corner you will see particularly the Pedro Miguel by-pass, which is naturally available in view of the topography at that point. The other plates do not require especial reference and I would revert to the harbor plate of Panama, VII. The relief maps which are hung in the other room show the reasons that led me to adopt a different alignment, and in this connection, with reference to the rock and earth filled dams, I want to say that with the heads that are provided I would be enabled to use hydraulic dredges, but submit that some work also should be done dry, as I have done on several occasions, so that the time of executing such dikes and low-head dams as I have indicated would be minimized.

I think there is nothing else which the speaker cares at this time to say. There remains little that he can do, but perhaps to stand on the very spots where he would found his proposed works and state his way of executing them. I will say that if there is anything else that he can do his services are at command.

The Chairman then stated that he desired some information concerning the east breakwater at Panama. It does not appear from Plate VII that any water would be inclosed of depth sufficient for deep-sea vessels. The west breakwater would certainly seem to prevent the sand drift which is known to exist in this part of Panama Bay. Would it not be possible to omit the east breakwater?

Mr. Bates. I would say that it would be possible, perhaps, to do so. There is a large excess of rock to be taken from the cuttings and it seems to me that this would be a good place of deposit for it and make a highly advantageous and inclosed harbor.

The Chairman. You look for a large growth in the city of Panama?

Mr. Bates. I think so. For instance, I have had occasion lately to know something about the possibilities of iron and coal in northern Peru, and it would appear that there are large deposits of ore as well as oil in northern Peru. The former compares favorably with the best character of iron ore found along Lake Superior, and these and other resources might mean a very large traffic to the canal.

Mr. Ripley. A statement was made that it costs from five to ten times as much for submerged-rock excavation as it does for rock excavation in the dry. I would like to ask for information concerning these prices.

Mr. Bates. It is a matter of depth and conditions. The depth, for instance, in the Hay Lake channel is about 20 to 22 feet.

The prices for submerged-rock excavation vary according to the texture and character of the rock, the price of coal, and the cost of labor, etc., in different parts of the world. The price ranges from $2.50 to $5, $6, and $7 per cubic yard.

Mr. RIPLEY. On the St. Marys River we have moved over one million and a half yards of sandstone rock, and the price did not exceed $2 a yard in any case. A great part of the work was done for $1.50 and in some instances for less than $1. Limestone rock cost $2.43 for a contract of a little over 100,000 yards, and we now have a contract for 1,750,000 yards in the dry, which will cost $1.36 a yard.

Mr. BATES. That is a little higher than on the Chicago Drainage Canal. The average price there was $1.10.

Mr. RANDOLPH. No; you are mistaken, the average cost was 76 cents.

Mr. BATES. I am glad to accept the correction.

Mr. RIPLEY. As I understand your statement, the excavation of rock by the submerged process is from five to ten times as much as it would be in the dry.

Mr. BATES. No, sir; five to ten times as much as ordinary dredging. Thus, for instance, the average price of dredging would be 25 cents.

Mr. RIPLEY. I thought you were referring to dry excavation of rock.

Mr. HUNTER. I understood you to say that, too. I thought that you said that the removal of rock under water cost five times as much as the removal of rock in the dry.

Mr. BATES. No, sir.

Mr. Hunter then spoke about several millions of cubic yards of rock to be removed in the Manchester Ship Canal at an ultimate depth of 29 feet, and that the cost, figured according to a certain method which had been adopted, would be just under 50 cents a yard.

Mr. BATES. Then you are using the Lobnitz system, which I am just about to introduce in the Hudson River. It is very applicable to sandstone rock.

I would hesitate to place an estimate upon a Lobnitz machine, where I had to deal with 100 million cubic yards of material wherein I had to handle isthmian rock, because the best of these machines are only able to average about 20 cubic yards per hour, and while the operating cost may be similar to that quoted, the plant installation to deal with 100 million cubic yards of submerged rock would be stupendous.

Mr. HUNTER. That is only a matter of multiplication of units, which is only a matter of detail.

There was one point that I noted when I read this pamphlet, which I did as carefully as I could. It is a little difficult to remember it all. It is somewhat merciless in its detail, but one of the fundamental points in your argument is, as I understand the pamphlet, that the basins which you propose to create by the action of the dams, whether at Gamboa or at Alhajuela, shall always be kept empty.

Mr. BATES. Except as to the silt ponds.

Mr. HUNTER. Do you rely upon the emptiness of the basin?

Mr. BATES. No, sir.

Mr. HUNTER. I will tell you my difficulty. It seems to me that your empty-basin system would be effective and suitable for this purpose if it were empty when the flood came, but suppose that you had two storm floods in succession—that you had two floods so near together that you could not discharge the first before you were troubled with the second. That was the difficulty.

Mr. BATES. Here, sir, is the point. When you have a divided channel you have, say, 16,000 square feet of waterway. At the velocity of 3 feet a second you could discharge 48,000 cubic feet per second, meaning a velocity of 1.7 knots per hour.

I will admit that if you had any such double flood, one following on top of the other, you then would, for a brief period, be obliged to allow more than 44,000 cubic feet per second to pass through. You can see exactly what it means on Plate IX.

General ABBOT. I would like to ask Mr. Bates if there is a correction necessary on page 62, as follows:

> In the present state of the art, submerged-rock excavation costs eight times as much as dry.

Does that mean dry earth? Should the word "earth" be added after "dry?"

Mr. BATES. It means dry earth, such as we had in the drainage canal of Chicago, where it cost about 18 cents. It is quite true that a correction making the text to read "two to eight," etc., might be advisedly made when the phrase is understood to refer to rock in the dry. As a matter of fact, the actual cost of rock to the contractor may be stated to run about 45 or 50 cents in the dry, if it be all limestone rock. The average contractor's price for submerged-rock excavation runs about four or five dollars, and from that standpoint the statement is perfectly correct as it stands.

Mr. Stearns then asked about the construction of the Gamboa dam with reference to the retention of silt.

Mr. BATES. I would raise the level of the floor of the sluices so that the water would be backed up for a mile and a half, catching as much of the silt as would deposit.

In the silt pond above the dam I would place an ordinary hydraulic dredge which would excavate accumulations of silt and pipe them through the dam into a steam hopper barge in the Obispo basin. This self-discharging barge would have capacity of three or four thousand tons and could steam to any convenient depositing area.

I might say that at Galveston, Tex., we are excavating material (about 10 million yards) and making a round trip of about 9 miles and distributing it from stations on the shore of a canal run into the city, over the site of the city, at an average cost last month of about 7½ cents.

Mr. STEARNS. How is the distribution effected from the dredge?

Mr. BATES. Inside the hull is a trunk, and on either side of this trunk are two parallel waterways, the suction pipe being connected with these trunks so that the same apparatus which loads the vessels unloads it.

Mr. HUNTER. Going back to the point which I raised, it appears to me to be of some importance as to the succession of two floods. Did I understand you to say that in such case it will be necessary to discharge all the flood water into the canal, sending part to the Atlantic and part to the Pacific? Would it be necessary to discharge it with such velocity as to interfere with navigation?

Mr. BATES. I think I will have to ask one question. What is the volume of the succession of the floods that you assume?

Mr. HUNTER. I am not assuming anything, except that before you are able to discharge the first flood which has filled your basins you have a second flood upon you, and it is absolutely necessary for you to discharge the water of the first flood, and therefore you would have to discharge such a quantity that you would turn out water into your canal at such a rate that the velocity would be four or five miles per hour.

Mr. BATES. If you assume a double flood at the height of 1879—in any such event, then it would be wise and prudent, for perhaps twenty-four hours once in a generation, to let a current of 6 feet a second pass through, but such an event has never transpired, and there is no evidence in the records that it ever will transpire.

Mr. HUNTER. With reference to the Mindi dam, are there borings on that site?

Mr. BATES. Yes; they were taken by the Commission.

Mr. HUNTER. Have you any records on the site of the dam on the Pacific side? I was unable to follow your plan very closely, and perhaps it would be of interest to tell us a little more about that dam.

Mr. BATES. You will find this on Plate VII. On the east side you have at Sosa Hill one abutment, and on the west side you have what I call West Rio Grande Hill. It has no name that I know. The distance across here is about 4,300 or 4,400 feet; not quite a mile. Borings have been taken particularly in the vicinity of La Boca. An excavation was made westward for a distance of about 400 feet and the evidence shows rock bottom nowhere far from the surface. The rock line varies from 35 to 68 feet.

The Chairman then mentioned as a matter of personal observation, that at the head of La Boca pier the rock was covered by 17 feet of water at low tide before it was excavated, and that it comes to the surface about 400 yards east of that.

Mr. STEARNS. You said something about first-class rock. Where would the first-class rock come from?

Mr. BATES. It would come from the Culebra section. You will find, for instance, at Culebra they have some rather good rock in some places. In some of my Australian work what we meant by first-class rock was rock that weighed from eight to twenty tons; and third-class rock was about one man to two man rock.

Mr. Welcker then inquired as to the navigable capacity of the canal. He desired an expression of Mr. Bates's opinion on tonnage.

Mr. BATES. On the upper left-hand figure of Plate XIII you will find it. You will there see the figures which I have used in order to get some sort of a basis as to the increment of growth. The Commission's report of 1901 took a period of growth with the Suez Canal which worked out a percentage considerably higher than I believe was proper. We start this canal with 7 million tons, and in order to make a proper comparison we should take that period of the Suez Canal's growth which also started with 7 million tons, and then the decade increment works out about 45 per cent. If you take that basis then you will perhaps come as near to gauging the future of the canal as it is possible to come, and that would mean that you would have in thirty years 250 per cent of 7 million, which would be 17½ million, using the said increment.

Mr. WELCKER. You state that this is the maximum?

Mr. BATES. No, sir; I believe that with the increase of population of the United States, etc., and what I have seen myself of Australia and New Zealand and the Orient, any lock canal should have a capacity of not less than 50 million tons.

Mr. WELCKER. I think that the Suez Canal has that capacity.

Mr. BATES. Yes, sir.

The CHAIRMAN. You speak of lake navigation on Lake Chagres—that a vessel has a certain number of miles of lake navigation. How much of that is in water with a natural depth of 40 feet?

Mr. BATES. If you take a level of + 33, then you would have about 7 feet of a submerged channel, but I call it lake navigation where the water has a chance to get past the vessel as she steams ahead.

The CHAIRMAN. The same as at Lake St. Clair, near Detroit?

Mr. BATES. Yes, sir; that I call lake navigation, because the water can get away.

The CHAIRMAN. The Gatun cut-off, will that permit a mile and two-tenths shortening without excavation?

Mr. BATES. If you make that level with an elevation of 62.5. You will see the profile in the plates; it is Plate XI. You will find one high point in the profile which is right opposite Tiger Hill. This point comes up to about 52. It is perhaps true that by making a detour you could avoid any digging at all. I think that it might be pertinent to call your attention to page 141 in the pamphlet, in which I have analyzed the curvature of the alignment under the different projects. The conclusions drawn therefrom are that the length of my waterway is the shortest by at least 4.82 statute miles; that the total curvature is from 139° 28′ to 224° 40′ less than proposed by the Commission of 1901. The curved courses are from 5.87 to 7.12 miles shorter. You will see in the last two columns the comparative curvature and alignment as affecting navigation; that is, when a curve happens in a submerged channel the vessel is not obliged to reduce its speed as it is in a restricted channel. The consequence is that the greater lake navigation you can have the less the curvature affects navigation.

The CHAIRMAN. What is your smallest radius?

Mr. BATES. The smallest is the one used in the old alignment of the canal itself. In no place have I used a radius which was smaller than that appearing in the old location.

Mr. RIPLEY. I see that you have used a speed of one-half mile less in the curves than in the tangents. Is that from observation or from guesswork?

Mr. BATES. I took for that statement the basis taken in the Deep Waterways Commission Report, which is likewise embodied in the Isthmian Report of 1901. I will say, however, that

the navigation officers of the *Kentucky*, in going through the Suez Canal, told me that they could make better speed in the curves than in the tangents.

Mr. RIPLEY. The curves are wider than the straight reaches in the Suez?

Mr. BATES. Yes.

The CHAIRMAN. On page 135, you speak of sanitation. In the third line of the second paragraph is the expression, "The death fee for all ages must be paid to this swamp passage." Now, as the passage will occupy ten hours or less, how much greater is the jeopardy to the passenger of the vessel than to the passenger on the railway train, say about as three hours is related to ten? Is not your statement drawing it strong?

Mr. BATES. Perhaps a little, but on the other hand I think the mosquitoes are a little strong down there too.

The CHAIRMAN. Did you ever take the trouble to investigate the truth of the statement you refer to about one dead man to each cross-tie during the building of the Panama Railroad?

Mr. BATES. Yes, sir; and I concluded that legend should be changed to about one man to every railroad rail.

The CHAIRMAN. There never was a more extravagant exaggeration than that.

Mr. BATES. Yet it has been published to the world.

The CHAIRMAN. The health record at Panama, stated in broad terms, has been good as respects the number of men sick constantly out of the employed force.

Mr. BATES. Did you not think that the percentage of men continuously on the pay roll at Panama would be very much less than on the drainage canal at Chicago—in other words, the force would be more constantly changing?

The CHAIRMAN. Yes.

On page 163, "New projects; estimates of cost," you give for plan A 145 millions, and other figures for the other plans. I take it to mean that you think that for 145 million dollars a contractor under the Government method of financing could safely take the work at those figures.

Mr. BATES. Yes, sir.

The CHAIRMAN. Does that contain a margin for contingencies?

Mr. BATES. Yes, sir.

The CHAIRMAN. "Administration and sanitation." Does the word "administration" apply to the carrying on of the government of the Canal Zone or to the canal work?

Mr. BATES. Such as the work of the administration in the Chicago Drainage Canal, and it does include sanitation. I think the problem of sanitation is very much simplified.

The Chairman then referred to the title page and a notation there respecting copyright and reservation of professional rights, and asked for an explanation as to its significance and its import to this Board or to the Government.

Mr. BATES. When I undertook to do this business I stipulated that if I produced something that was of value to the Government, and if it were adopted, I should be compensated for it as professional work, and a promise was made that such compensation would be appraised by such a board as this. If nothing was adopted, I took the risk and merely contributed as much as I could to the solution of the problem which would be dealt with. That is the import.

The CHAIRMAN. Thank you.

Mr. HUNTER. Would you be prepared to take a contract for this project at your estimate of 145 millions?

Mr. BATES. I should be very glad to, or I would take it on a mileage basis.

The CHAIRMAN. Is this 145 millions for a canal 195 feet wide, and more in certain places, on the bottom and 40 feet deep throughout?

Mr. BATES. Yes, sir.

The CHAIRMAN. What about a guaranty for a period of years, say ten years after completion?

Mr. BATES. That would probably be a matter of negotiation.

Mr. HUNTER. The principal consideration, Mr. Bates, is that of time. Would you undertake to do it in seven years?

Mr. BATES. I think it can be done in that time.

Mr. HUNTER. Seven years from next March?

Mr. BATES. I think so.

The CHAIRMAN. Penalty for failure?

Mr. BATES. I may say that before I formulated that project, I talked with a few of my friends and they thought I was about right.

The CHAIRMAN. Some engineers have said that with the soft material of clay or blue clay in the bottom of Culebra the screw of the propeller would stir up the mud, which would be swept away by the current and leave the banks undermined, to result in slides.

Mr. BATES. I do not think there is any more danger than might exist in other situations where materials are similar.

The CHAIRMAN. If you were the contractor, would you run your own line of ships from New York to Colon?

Mr. BATES. If I could not get suitable competition. I may say in that connection that I do not believe the Government of the United States should perform its functions through the medium of a State-chartered corporation.

The CHAIRMAN. You think the outer breakwater at Limon is unnecessary?

Mr. BATES. Yes, sir.

The CHAIRMAN. Any other questions, gentlemen?

Mr. WELCKER. Referring to Plate VI, concerning the proposed town and naval station, do you think an enlargement should be made here [pointing to an angle near the shore line]?

Mr. BATES. I do think so. I think the area might be enlarged. You will understand Mr. Welcker, that I did not draw these as finalities.

There is one interesting point that I might call to your attention while you are looking at the plate (Plate VI). I am not at all sure that there is not a pass to the southward of the Jaramillo Hill whereby that line might actually be straightened. The only evidence for that, however, is a survey by Captain Peacock in 1831–32. He speaks of landing on what is known as Limon Point and he names it Peacock Point; he found there 3½ fathoms of water. There is a little village which I have seen, near the mouth of an incoming stream, and in his book he speaks of having taken a native guide with him across to Gatun. His language would appear to indicate that the same is worthy of examination, although he gives no elevations.

The CHAIRMAN. Have you seen that large map of Totten's, of 1857?* He gives much topography hereabouts not found on other maps.

Mr. BATES. No; I have not.

The CHAIRMAN. They have one here.

Mr. BATES. I would be very glad to see it. I have seen a great many of the old maps of the Panama Railway. They are in the rooms of the Geographical Society, in New York. I have had access to the notes which my uncle made at the time of the construction of the Barbacoas Bridge under Totten. He had charge of the building of this bridge.

The CHAIRMAN. If there is nothing further we will excuse Mr. Bates, thanking him for his attention, which I know the members appreciate.

APPENDIX 1.

Minute re lockage supply and capacity—Projects A, B, and B′, Panama Canal.

The following is a synopsis of a study which was made for project A at a level of +20.

Basins.	Elevation.	Area in square miles.	Acres.
Lake Chagres.....	20.0	29.5	18,880
Lake Panama.....	20.0	7.0	4,480
Lake Gamboa.....	108.8	9.4	6,016
Lake Alhajuela.....	170.5	5.0	3,200
Canal	20.0	1.5	960
			33,536

Storage of basins.

Lakes Chagres and Panama and canal per foot of height above 20 feet, 18,880 + 4,480 + 960 = 24,320 acre-feet, a figure which is ultraconservative.

Low water in the Chagres.

Enough data exist to estimate the discharge at Bohio for each of the years 1890 to 1904, inclusive.

The driest year was 1903.

The three dry months of all years are February, March, and April.

In 1903 the discharge at Bohio was as follows: [a]

	Cubic feet per second.
February	1,024
March	636
April	565
Average	742

New Panama Canal records estimate the contribution of the river at Bohio for the ninety days of minimum flow at 700 cubic feet per second.

A. P. Davis, Isthmian Canal Commission Report, Appendix, page 46, estimates the minimum flow for ninety days at Bohio at 600 cubic feet per second.

But in addition to the flow at Bohio we have the contributions to Lakes Chagres and Panama of the Rio Grande and of the watershed of Chagres between Bohio and Mindi. In the latter, the two large streams Trinidad and Gatuncillo are by far the most important.

In 1900 the Isthmian Canal Commission gauged the rivers Grande, Trinidad, and Gatuncillo. During February, March, and April the flow of the Grande was insignificant, less than 1 cubic foot per second. The average flow of the Gatuncillo and Trinidad for the same period was 155 and 229 cubic feet per second, respectively. The average flow at Bohio was 793 cubic feet per second. Therefore the dry-season discharge of these two streams is 57 per cent of the discharge of the Chagres at Bohio. It will be safe to assume that the minimum flow into Lakes Chagres and Panama for ninety days will never be less than 1,000 cubic feet per second, and will probably be 10 per cent to 20 per cent higher.

Requirements of the water supply.

For the rate of evaporation from the surface of lakes and canal the Comité Technique uses 0.24 inch per twenty-four hours. The evaporation from Lake Nicaragua (Commission Report, Appendix, p. 186) was found to be 0.204 inch per twenty-four hours. For the area of Lakes Chagres and Panama and the canal the evaporation at 0.24 inch per twenty-four hours is approximately 280 cubic feet per second.

Taking the locks at 20 by 105 by 1,050, the passage of a single ship using full locks would require 51 cubic feet per second and using half locks 25.5 cubic feet per second.

By 1917 it has been assumed that the yearly traffic will be 7,297,000 tons, which could be carried by, say, 8 small and 2 large ships per day, averaging about 2,000 net tons per vessel, and requiring 306 cubic feet per second.

Adopting the figures of the Isthmian Canal Commission for leakage, we then have for consumption:

	Cubic feet per second.
Lockage	306
Evaporation	280
Leakage	257
Total	843

The surplus for the three dry months is at least 157 cubic feet per second. No deduction is made for power, as any tailrace from a water-power plant will flow into the end lakes.

Therefore locking such ships one by one and without recourse to storage, and only natural inflow taken at the minimum, the capacity of project A at a 20-foot level is, during the driest season, 11,000,000 tons per annum. Reckoning the storage of Lake Chagres, Lake Panama, and the canal, it may be remarked that in round figures 7½ inches of storage will raise the above rating capacity about 2,500,000 tons. In addition a certain amount of storage could safely be impounded in the basins made by the Alhajuela, Gamboa, and Caño dams without interference with their functions.

The 1903 average at the Suez Canal is 3,166 tons per transit ship, and this average has risen steadily during the past twenty years at the rate of 70 tons per annum. For the last decade it has advanced 91 tons yearly. In 1917 the average will, at these increments, be 4,146 tons or most probably 4,500 tons.

It will require actually less lockage water to pass ten vessels of the average size because of their increased displacement, so that the transit capacity may well be by the single ship locking system $11{,}000{,}000 \times \frac{4{,}500}{2{,}000}$, or at the rate of 27,500,000 tons, without recourse to storage, and proportionately more when utilizing the lake storage.

[a] New Panama Canal Company.

But this is not all. The locks are to be of ample size to employ in many instances the two ships or the group system of locking, as at the "Soo" Canal. Such systems are capable of again doubling the transit rate without demanding more water, rather actually less.

When the level of A is raised to, say, +27, the area of the end lakes and the canal surface is largely augmented, consequently the tonnage capacity per inch of storage is increased and the total lockage capacity of the canal under this plan. It is safe to say that the capacity of project A at 27, all things considered, is equal to the demands of many generations to come. Naturally, on account of the different lift of the locks, the detailed figures work out somewhat differently than for the 20.

Project B, which was recommended in the brochure, has a far greater lake and natural storage area and practically the same inflow, so that its lockage is still higher, and variations from the standard level are least for the largest capacity.

When one considers the possibilities of storage in the navigated lakes and canal its transit capacity is more than can be required for centuries. On the upper waters of the Pequeni, Chagres, Trinidad, and Gatuncillo supplemental storage reservoirs are practicable if such are ever wanted in the far distant future. It is intended that the levels of the lakes shall be so regulated as to best serve the anticipated demands of transit tonnage as they arise. The various structures should be designed to admit of this regulation, but that variation should not run over 5 feet above and 2 feet below the standard level.

Project B′ (6-lock canal) is more limited as to the natural capacity than B or A, because it does not on the upper and controlling level have the contributions of the watershed below Bohio. Therefore, while its capacity is ample for a long time to come, and it is cheaper to build, it has not been favored. The writer has wanted to see the very best plan, all things considered, adopted. In preparing the brochure it was seen that as to lockage capacity there was demonstrably a great sufficiency. It would have been set forth also mathematically if there had been official contours located which disclosed accurately the lake areas.

For example, the area of the water surface above the Gatun dam, project B, running well up the valleys of the Trinidad, Gatuncillo, Caño, Gigante, and Chagres to Alhajuela Canal and Pedro Miguel, etc., certainly aggregates over 100 square miles—64,000 acres.

The evaporation for this area for ninety days at 0.24 inch per twenty-four hours is 21.6 inches or 1.8 feet. If the standard level is 62.5 feet one may start the dry season with, say, a 67.3 elevation and end it at +61.5; then there would be 4 feet of available storage, or $64{,}000 \times 4 = 256{,}000$ acre-feet, which is equal to 1,434 cubic feet per second for ninety days. With the inflow of 1,000 cubic feet per second there is a total of 2,434 cubic feet per second. Deducting 257 cubic feet per second for leakage there remains available for lockage 2,177 cubic feet per second. This amount, at 54 cubic feet per second per ship, would suffice for the passage of 40 vessels singly. If they average 4,500 tons each, the rate is 180,000 tons per diem, or for ninety days a total of 16,200,000 tons—at the rate of 64,800,000 tons per annum. By the two-ship or group-locking system the transit capacity is still greater. During the rainy season as the inflow is more the real annual capacity of a lock canal built under the projects is obviously higher than indicated. Naturally all such figuring is academic. But one may summarize as to the lockage supply of projects B, A, and B′:

That the inflow and storage capacity of the lake canal within the range of admissible and moderate variations of level is more than ample for the future demands of isthmian commerce having regard for—

(*a*) The increasing average size of ships.

(*b*) The water conserving possibilities of the group system of lockage.

(*c*) The feasibility of storage without interfering with the regulating functions of the dams.

The writer concludes that it is doubtful if the demands on storage will ever occasion variations of level of over 2 feet exclusive of provisions for evaporation.

The greatest strain on the capacity of the canal would result probably from a military or naval necessity. By using the twin-lock and the group system it would be perfectly feasible to lock and pass 40 battle ships and as many torpedo boats from ocean to ocean in a day and every day at the dry season at the expenditure of half an inch per diem of stored water from the great lake area of project B.

Appendix 2.

Prices for the execution of the principal works of A, B, and B′ supplementary to table on page 163 of the "Panama Canal System and Projects."

PREMISES.

The prices herein presented are based upon the following premises:

I. A contract for the engineering execution of a definite project, with fully specified works, to be completed in a certain time, at a prescribed rate, with a proper programme of execution, with acceptable terms and times of payment, under suitable guaranties and proper inspection.

II. Free right of way for all operations. Exemption from taxes, dues, duties at the Isthmus, imports of United States Government, Republic of Panama, State or municipal charges of any kind.

III. Free use and consumption for general purposes of all Government property, material, plant, etc., at the Isthmus, or purchased therefor.

IV. The free use of Panama Railway and its property through a contract with the Government to execute its public service, to transport passengers, freight, mail, express matter, locally and across the Isthmus, for fixed prices

per passenger and ton mile; to equip, extend, maintain, and operate the railway for the time of canal construction, the Government to take care of the bonds. All through rates of traffic agreements to be abrogated and a spot-cash system at the Isthmus substituted.

V. The Government of the Zone to have the care and expense of hospitals, sanitation, and policing, and regulation of the liquor traffic.

VI. Contractors' employees to work and to be paid by the hour.

VII. Reenforced concrete to be employed in structural designs where practicable instead of masonry or solid concrete. Designs to be approved by Government.

BALBOA HARBOR—EXCAVATED MATERIAL, PART DEPOSITED AT SEA, PART PLACED ASHORE ON RECLAMATIONS, OR IN MINDI DAM.

[Item 1, page 163.]

Sec.	Location.	Cubic yards.	Rate.	Amount.	Remarks.
1	Forty-foot contour to shore, 600 feet wide	11,250,000	.....	.....	Hopper dredge work, shore discharge.
2	Shore to basin	2,500,000	.....	.....	Suction dredge pipe, shore discharge.
3	Basin to lock	6,850,000	.....	.....	Suction dredge pipe, discharge ashore.
4	Total	20,600,000	$0.167	$3,420,000	
	Mindi lock and barrage (cubic feet)	16,200,000	0.40	6,480,000	
	Mindi dam	.....	.....	.....	Combined dredge and train service.
	Two-thirds earth (cubic yards)	1,500,000	.....	.....	Earth from channel.
	One-third rock (linear feet)	4,000	.....	100,000	Rock from lock site.
	Total	.....	.....	10,000,000	

GATUN—DAM, LOCK, BARRAGE.

Projects B, B'.

[Item II, page 163.]

Dam.

From lock, 683,287 cubic yards	.....
Earth, hydraulic fill, etc., 1,000,000 cubic yards, at 27½ cents	$275,000
Material, rock and earth from Culebra and lock site, 2,952,500 cubic yards, at 15 cents.	442,875
Total cubic yards, 4,635,787	742,875
Miscellaneous, 4,500 feet, at $25	112,500
	830,375

Gatun lock and barrage.

16,470,000 cubic feet, at $0.405	$6,670,350
Total	7,500,725
Round	7,500,000

PEDRO MIGUEL—LOCK, BARRAGE, AND BY-PASS.

Project B.

[Item III, page 163.]

Lock and barrage, 15,930,000 cubic feet, at 41 cents	$6,531,300
Excavation, by-pass, 1,000,000, at 47 cents	470,000
Total	7,001,300
Round	7,000,000

Project B'.

Double flight locks and barrage, 27,000,000 cubic feet, at 38 cents	$10,260,000
Round	10,250,000

EXCAVATION.

Project A.

[Item IV, page 163.]

Old alignment:	
Mindi to Pedro Miguel, 145,000,000 cubic yards, at 57.24 cents	$83,000,000
Allowance for bank protection or excavation in lieu thereof	10,000,000
Total	93,000,000

The above includes the Obispo basin and channel compensation.

NOTE I.—Alignment via Gatun cut-off:	
The above yardage is increased (mostly by ordinary dredging work), if the Gatun cut-off be adopted in project A, to a total of 167,000,000 cubic yards, at 55 cents, or	$92,800,000

If the Culebra retaining walls are not required, the Gatun cut-off, saving 1.4 statute miles, may be adopted, and the cost falls within the $93,000,000 of Item IV.

NOTE II.—It must be borne in mind that during the past eighteen months large sums have been expended on the Isthmus, and the value of this work reduces the unit prices of Item IV.

EXCAVATION.

Project B.

[Item IV, page 163.]

New alignment via Gatun cut-off:	
Mindi to Pedro Miguel, 73,000,000 cubic yards, at 81.85 cents	$59,750,000
Allowance for contingencies of bank protection or extra excavation	10,000,000
Total	69,750,000

The above cubic yards include the Obispo basin and channel compensation.

Project B′.

New alignment:	
Mindi to Pedro Miguel, 55,000,000 cubic yards, at 81.81 cents	$45,000,000

NOTE.—B′. It is not considered that retaining wall is necessary with summit level at +97.5. If such is required when cut is opened to the depth at +57.5, suitable costs must be added for this project.

NOTE.—A. The large amount of dredging averages down the cost per cubic yard.

The side slopes of the Culebra division are taken as 1 to 1, as used by the Comité Technique and the Isthmian Commission of 1901. With flatter slopes the above quantities will be materially increased.

PANAMA HARBOR AND SOSA LOCK.

Projects A, B, B′.

[Item V, page 163.]

Sosa lock and barrage, 16,500,000 cubic feet, at 40 cents		$6,600,000
Excavation:		
Forty-five-foot contour to park	6,600,000 cubic yards	
Park to shore line	8,600,000 cubic yards	
Shore line to lock	230,000 cubic yards	
Total	15,430,000 cubic yards at 22 cents	3,394,000
Total		9,994,000
Round		10,000,000

NOTE.—Allowance for extra hard material seaward from lock among miscellaneous, Item IX.

PEDRO MIGUEL TO SOSA.

Projects A, B, B′.

[Item VI, page 163.]

Sosa junction	6,100,000 cubic yards	
Junction to Pedro Miguel	3,300,000 cubic yards	
Total	9,400,000 cubic yards, at 32 cents	$3,008,000
Round		3,000,000

PANAMA RAILWAY CHANGES.

Project A.

[Item VII, page 163.]

18 miles, at $40,000	$720,000
14 miles grade raising, at $10,000 per mile	140,000
Miscellaneous	140,000
	1,000,000

Project B (Gatun dam and ferry).

25 miles, at $40,000 per mile	$1,000,000
3 miles grading, Mindi to Gatun 3 miles grading, Panama section	60,000
Miscellaneous	190,000
	1,250,000

Project B′ practically same as B.

DAMS—ALHAJUELA, GAMBOA, CAÑO.

Projects A, B, B′.

[Item VIII, page 163.]

A and B.

Place.	Quantity.	Rate.	Amount.	Remarks.
	Cubic yards.			
Alhajuela	80,000	$21.50	$1,270,000	Inclusive of care of river during construction period.
Gamboa	280,000	15.00	4,200,000	
Caño	80,000	19.00	1,520,000	
Silt provisions, etc.			560,000	
Total			8,000,000	

NOTE.—In project B′ the controlling dams are changed to sites satisfying the upper lake level contour of 97.5. Thus there would be a—

Dam at Alhajuela.

Dam on the Pequeni.

Dam on the Chagres above junction of Pequeni.

Dam on Caño.

The expense of these dams falls safely within the allowed $8,000,000. On the other hand, except for lockage supply only, the Alhajuela dam may be retained, as the large lake area at 97.5 forms an effectual flood control and the dams on the Pequeni and upper Chagres are controlling as well as lockage reservoir dams. Such are desirable to increase the feed of B′ during the dry season.

MISCELLANEOUS.

Projects A, B, B′.

[Item IX, page 163.]

Balboa docks, 10,000 feet, at $100	$1,000,000
Clearing old canal to Mindi, 1,000,000 cubic yards, at 15 cents	150,000
Chagres dam, 2,000,000 at $15 Chagres dam, 1,000,000 at $1	1,400,000
Sheeting, 100,000	300,000
Old pipe line.	
Light-house signals	100,000
Panama docks, 5,000 feet, at $100	500,000
La Boca dike, 1,300,000 cubic yards, at 30 cents (for miscellaneous items) (material and haul on Culebra account)	390,000
Panama breakwater between islands	300,000
East and west breakwater (material and haul on Culebra account)	.....
Limon breakwater, 666,000 cubic yards, at $1.50 (material by train and barge for excavations)	1,000,000
Naval and turning basins, Balboa and Panama, 3,000,000 cubic yards	480,000
Railway extensions to Atlantic and Pacific breakwaters, 10 miles, at $30,000	300,000
Construction depots, wharves, structures	1,000,000
Miscellaneous débris dams	500,000
Buoys, guide piles, ranges, etc	100,000

BOHIO—DAM, LOCK, AND BARRAGE.

Project B'.

[Item X.]

Bohio dam.

Class.	Quantity.	Rate.	Amount.	Remarks.
	Cubic yards.			
Earth	758,797			Material by train from excavations.
Rock	448,357			Bottom by dredge work.
	1,187,154			
	1,200,000	$0.25	$300,000	
Miscellaneous, feet	1,200	.30	36,000	
Total			336,000	
Bohio lock and barrage:				
16,632,000 cubic feet at 40 cents			6,652,800	
Total			6,988,800	

APPENDIX H.

DEPTHS OF HARBORS.

TABLE I.—DEPTHS THAT CAN BE CARRIED INTO 50 COMMERCIAL AND NAVIGABLE HARBORS OF THE WORLD.

[Furnished by H. M. Hodges, Captain, U. S. Navy (retired), Hydrographer.]

Location.	Mean low water.	Lowest high water—neaps.	Location.	Mean low water.	Lowest high water—neaps.
	Feet.	*Feet.*		*Feet.*	*Feet.*
Alexandria	31.0	31.5	Hongkong	36.0	38.5
Antwerp	21.0	31.5	Hull	22.0	36.5
Auckland	31.5	38.5	Kobé (at mooring buoy)	31.5	34,5
Belfast	21.0	28.0	Lisbon	42.0	49.0
Bombay	23.0	31.0	Liverpool	28.0	46.5
Boston	27.0	34.5	London (Royal Albert dock)	16.0	33.0
Bordeaux—Mouth of Gironde	28.5	38.5	Manila (at anchorage)	25 to 40.0	26.5 to 41.5
Bordeaux—Bec d'Ambes bar	11.6	21.6	Marseille (dock entrance)	54.0	54.0
Buenos Ayres	19.5	21.0	Melbourne (entrance to Port Philip)	30.0	31.5
Callao Harbor	24.0	26.0	New Orleans	25.0	25.0
Calcutta (Royapur bar)	15.0	22.0	New York (deeper channel being dredged)	30.0	33.0
Cape Town	36.0	39.0	Norfolk	28.0	30.0
Cardiff	3.0	27.0	Odessa (in harbor)	30.0	30.0
Charleston	27.0	31.0	Philadelphia	24.0	28.5
Constantinople	120.0	120.0	Rio Janeiro	45.0	48.0
Copenhagen	29.0	29.0	Rotterdam	22.0	26.5
Dunkirk	12.0	24.0	St. Petersburg	22.0	22.0
Galveston	22.0	22.0	San Francisco	48.0	51.5
Genoa (at quay)	42.0	42.0	Shanghai (Wusung anchorage)	17.0	22.0
Glasgow	21.0	29.0	Singapore (Keppel Harbor)	34.0	38.5
Gothenburg	23.0	23.0	Seattle	150.0	160.0
Habana	39.0	40.0	Sydney	32.0	35.0
Halifax	66.0	70.0	Trieste (mooring buoy)	48.0	49.0
Hamburg (dredging continuously carried on)	18.0	24.5	Vancouver	33.0	44.0
Havre (channel being dredged to 12 feet, mean low water)	9.0	25.0	Valparaiso	150.0	152.0
			Yokohama (in harbor)	31.0	54.0

TABLE II.—AVAILABLE DEPTHS FOR NAVIGATION OF 160 PRINCIPAL COMMERCIAL AND NAVAL HARBORS OF THE WORLD.

[Furnished by O. H. Tittmann, Superintendent Coast and Geodetic Survey.]

NORTH AMERICA.

Name.	Depth on bar or through entrance.		Remarks.
	Low water.[a]	Mean high water.	
	Feet.	*Feet.*	
Quebec, Canada	25	42	
Halifax, N.S	Unlimited.	.....	Over 60 feet.
St. John, N. B	21	44	
Portland, Me	36	45	Depth can be taken in from outside to anchorage below harbor; harbor dredged to 30 feet at low water or 39 feet at high water.

[a] Low water is the plane of the harbor chart in every case. Where the tidal inequality is considerable, this plane is mean lower low water or low water springs; where the inequality is small, the plane is mean low water.

TABLE II.—AVAILABLE DEPTHS FOR NAVIGATION OF 160 PRINCIPAL COMMERCIAL AND NAVAL HARBORS OF THE WORLD—Continued.

NORTH AMERICA—Continued.

Name.	Depth on bar or through entrance.		Remarks.
	Low water.	Mean high water.	
	Feet.	*Feet.*	
Boston, Mass	30	41	Improvements in progress to obtain 35 feet at low water or 46 feet at high water.
Newport, R. I	Unlimited.		Over 100 feet to sheltered anchorage west of Goat Island.
New York, N. Y	30	34½	Improvements in progress to obtain 40 feet at low water or 44½ feet at high water.
Philadelphia, Pa	23	29	Improvements in progress to obtain 30 feet at low water or 36 feet at high water.
Baltimore, Md	30	31	Recommended by U. S. Engineers 35 feet at low water or 36 feet at high water.
Hampton Roads, Va	30	32½	Least depth is found in Chesapeake Bay northwest of Lynnhaven Bay, and can be increased by dredging.
Wilmington, N. C	21	25	
Charleston, S. C	26	31	
Savannah River, Ga	19	26	Improvements in progress to obtain 21 feet at low water and 28 feet at high water.
Key West, Fla	27	28	
Tortugas Harbor, Fla	36 or more.		There is a narrow channel with 42 feet. Rise of tide 1 foot.
Pensacola, Fla	30	30	Near the time of the moon's greatest declination the range of tide is 1½ feet; at other times it is inappreciable.
Mobile, Ala	26	26	Improvements in progress to obtain 30 feet on bar. Near the time of the moon's greatest declination the range of tide is 1½ feet; at other times it is inappreciable.
Mississippi River, La.:			
South Pass	26	26	A narrow channel is maintained to a depth of 30 feet in middle and 26 feet at sides. Near the time of the moon's greatest declination the range of tide is 1½ feet; at other times it is inappreciable.
Southwest Pass			Improvements in progress to obtain 35 feet.
Galveston, Tex	28	28½	Improvements in progress to obtain 30 feet at low water.
Veracruz, Mexico	33	33½	
Habana, Cuba	39	40	
Guantanamo, Cuba	41	42	
St. Thomas, W. I	33	33½	
Acapulco, Mexico	Unlimited.		250 feet through entrance, decreasing to 70 or 80 feet at anchorage.
Colon	40	41	Depth found about three-fourths mile off Colon or 1½ miles from canal entrance, and thence deepens gradually seaward.
Panama	40	55	Depth found about 1½ miles eastward of the islands in Panama Roads and about 4 miles from canal entrance, and thence deepens seaward.
San Diego, Cal	28	33	
San Francisco:			
Main channel	33	38	Natural depths on bar.
South channel	36	41	
Bonita channel	45	50	
Columbia River	24	31	Improvements in progress to obtain 30 feet at low water or 37 feet at high water, and more if possible.
Seattle and Tacoma	Unlimited.		Depths 200 feet or more from sea to mooring buoys.
Esquimalt	48	55	Harbor depth is 36 to 38 feet at lowest low water.
Vancouver	31½	42	
Honolulu	30	31	Channel mostly dredged to 34 feet.

SOUTH AMERICA.

Cartagena, Colombia	60 or more.		
La Guaira, Venezuela	40	42	Open roadstead deepening rapidly seaward; breakwater shelters its east part. There is 40 feet or more just off breakwater, and 24 to 36 feet inside it.
Port of Spain, Trinidad	Unlimited.		Sheltered anchorage deepening gradually from shore; 36 feet at 2 miles off.
Para River, Brazil (east mouth of Amazon).	36	44	Depth uncertain; 18 feet at low water or 26 feet at high water to Para.
Bahia, Brazil	Unlimited.		Anchorage in 40 to 60 feet, as desired.
Pernambuco, Brazil	16	22	Bar and harbor to be deepened to 23 feet at low water or 29 feet at high water. Deep-draft vessels now anchor in 30 to 40 feet (low water) in the roadstead about three-fourths mile off.
Rio de Janeiro	48	51	
Santos, Brazil	30	35	A depth of 25 feet at low water or 30 feet at high water can be taken up to the city.
Montevideo, Uruguay	26	27½	Improvements in progress to form a port with stated depth. Montevideo is an open roadstead on north side of the broad estuary at the mouth of Rio de la Plata. A depth of 60 feet is found 30 miles from city, and thence it shoals very gradually to 30 feet about 3 miles off.
Buenos Ayres		26	

TABLE II.—AVAILABLE DEPTHS FOR NAVIGATION OF 160 PRINCIPAL COMMERCIAL AND NAVAL HARBORS OF THE WORLD—Continued.

SOUTH AMERICA—Continued.

Name.	Depth on bar or through entrance.		Remarks.
	Low water.	Mean high water.	
	Feet.	*Feet.*	
Valparaiso, Chile	Unlimited.	.....	Open bay, with deep water; depths 100 to 200 feet at anchorage and mooring buoys.
Callao, Peru	Unlimited.	.....	Open bay, with depths of 25 to 45 feet (low water) at anchorage. A depth of 24 feet at low water or 27 feet at high water at coal pier.
Guayaquil, Ecuador	12	21	The stated depth is on a bar in the river. Guayaquil is on Guayaquil River, which empties about 40 miles from the open sea at the head of the Gulf of Guayaquil. Both gulf and river are much obstructed by shoals. If well surveyed and marked, probably 33 feet or more (low water) could be taken through gulf to mouth of river.

BRITISH ISLANDS.

Cork Harbor (Queenstown)	41	50	31 feet at low water or 40 feet at high water to Queenstown.
Dublin	16	25	
Belfast	20	28	
Bristol:			
King Roads	42	69	
Avonmouth docks	1	32	38 feet on sill at high water springs and 29 feet at high water neaps.
Cardiff:			
Outer anchorage	42	69	
Cardiff Roads	16	43	
Deepest dock (1901)	2	29	38½ feet at high water springs; depth of dock, 32 to 39 feet.
Liverpool	27	47	
Manchester Ship Canal	26	26	Depth on sills, 28 feet.
Clyde River:			
Greenock anchorage	Unlimited.	.....	Depth at anchorage, 60 to 100 feet.
Greenock docks	23	31½	
Glasgow	23	31½	
Tay River (Dundee)	19	32½	
Firth of Forth	36	49	To anchorage, 1½ miles off Leith.
Leith docks	15	28	
Newcastle	22	32¾	
Humber River (Hull)	40	55	About 22 feet at low water or 38 feet at high water up to Hull.
Thames River:			
To Nore	38	51	
To Gravesend and Tilbury docks.	26	40	Improvements in progress to obtain 29½ feet at low water.
Portsmouth	26	37	
Southampton	30	39	
Plymouth and Hamoaze	29	41	

WEST EUROPE.

Stockholm, Sweden	26	26	Proposed 32½ feet.
Kronstadt, Russia	27	27	
St. Petersburg	22	22	To be deepened to 28 feet.
Riga, Russia	20	20	Bar dredged to 24 feet in 1901.
Danzig, Germany	26	26	24½ feet to city.
Stettin, Germany	29½	29½	22 feet to city.
Copenhagen, Denmark	29	29	
Christiania, Norway	Unlimited.	.....	
Elbe River, Germany:			
Brunshausen	24½	33¾	To be deepened to 32¾ feet at low water or 42 feet at high water.
Kaiser Wilhelm Canal	24½	33¾	Canal 29½ feet deep.
Hamburg	19½	25½	
Weser River, Germany:			
Bremerhaven	23	32	To be deepened to 26 feet at low water or 35 feet at high water.
Bremen	15	19	
Jade River (Wilhelmshaven)	34½	41	

TABLE II.—AVAILABLE DEPTHS FOR NAVIGATION OF 160 PRINCIPAL COMMERCIAL AND NAVAL HARBORS OF THE WORLD—Continued.

WEST EUROPE—Continued.

Name.	Depth on bar or through entrance.		Remarks.
	Low water.	Mean high water.	
	Feet.	*Feet.*	
Amsterdam, Holland (North Sea Canal).	29½	29½	Improvements in progress to obtain a depth of 33¾ feet.
Rotterdam, Holland	24½	30	
Schelde River:			
Flushing	29	41	
Antwerp	22	34	Improvements in progress to obtain 26 feet at low water or 38 feet at high water.
Dunkirk, France	12	25½	Improvements in progress to obtain 18¾ feet at low water or 32¼ feet at high water.
Havre, France	16	34½	Proposed to deepen channel to 29 feet at low water or 47½ feet at high water.
Cherbourg, France	36	52	
Brest, France	39	58	Breakwater harbor on north side of roadstead.
Roadstead	Unlimited.		Sheltered anchorage in 60 to 100 feet, and no less water to sea.
Gironde River, France (Bordeaux).	29	42	Vessels of 21 feet draft can go to Bordeaux at high water neaps and 27¼ feet at highest tides.
Tagus River, Portugal (Lisbon).	42	51	
Cadiz, Spain	32	41	

SOUTH EUROPE.

Gibraltar	Unlimited.		Open roadstead. Anchorage behind breakwater in 48 feet or less, as desired.
Barcelona, Spain	36	36	Depth in harbor, 20 to 66 feet.
Marseille, France	Unlimited.		The harbor consists of basins lying inside a breakwater which is parallel to the shore. The entrance at the north end of breakwater is over 90 feet deep. The depths on the sills between the basins are from 26¼ to 48 feet and in the basins from 19½ to 65 feet.
Toulon, France	Unlimited.		To an anchorage inside breakwater. The depths are 30 to 48 feet at the mooring buoys.
Genoa, Italy	60	60	Depths in harbor shoal from about 60 feet at entrance to between 23 and 42 feet at the quays.
Spezia, Italy	42	42	Harbor has depths of 30 to 42 feet.
Leghorn, Italy	25	25	To be dredged to 26¼ feet.
Naples, Italy	Unlimited.		Depths of 24 to 30 feet at mole.
Malta (Valetta)	72	72	Depths at anchorage, 30 to 78 feet, as desired.
Brindisi, Italy	32¾	32¾	
Venice, Italy	26	28	
Trieste, Austria	Unlimited.		Anchorage outside breakwater in 60 feet. Depths between piers inside breakwater, 30 to 48 feet.
Finme, Austria	Unlimited.		Depth in breakwater harbor, 54 to 108 feet.
Corinth Canal, Greece	26	26	
Saloniki, Turkey	Unlimited.		Anchorage close to city in 40 feet or more, as desired. Small breakwater harbor with 28 feet.
Constantinople	Unlimited.		
Dannbe River (Sulina mouth).	26	26	
Odessa, Russia	30	30	
Sevastopol, Russia	54	54	Anchorage in 54 feet or less.

AFRICA.

Tangier	Unlimited.		Open road; anchorage in 45 feet or less.
Algiers	60	60	Breakwater harbor; anchorage 60 feet or less.
Tunis Canal	21	21	
Tripoli	22	22	Natural channel through reefs.
Alexandria	30	30	
Suez Canal	29½	29½	To be deepened to 31 feet.
Zanzibar	36	47	Several channels, depths 33 to 39 feet (low water).
Port Natal (Durban)	24	29	Entrance between jetties.
Algoa Bay (Port Elizabeth).	Unlimited.		Open roadstead; 33 to 42 feet (low water) at anchorage.
Table Bay (Cape Town)	35	38½	Breakwater harbor. Depth at jetties, 20 to 30 feet at low water.

TABLE II.—AVAILABLE DEPTHS FOR NAVIGATION OF 160 PRINCIPAL COMMERCIAL AND NAVAL HARBORS OF THE WORLD—Continued.

ASIA.

Name.	Depth on bar or through entrance.		Remarks.
	Low water.	Mean high water.	
	Feet.	*Feet.*	
Smyrna, Turkey	36	36	Depth in harbor, 25 to 36 feet.
Aden	26	30½	To be deepened to 30 feet at low water.
Bombay, India	29	40	To anchorage. Deepest dock has 30½ feet on sill at high water.
Colombo, Ceylon	36	37½	Depth in harbor, 26 to 36 feet (low water).
Madras, India	42	44	Anchorage in harbor in 36 feet or less (low water).
Calcutta, India	22	34	To Calcutta, 15 feet at low water or 27 feet at high water.
Rangoon, Burma	11	25	In 1901 the greatest draft vessel taken to Rangoon was 27 feet.
Penang	24	31	
Singapore	36	41	18 to 40 feet (low water) at wharves.
Batavia, Java	Unlimited.	.....	Roadstead; anchor in 36 feet or more, as desired.
Manila	Unlimited.	.....	36 feet found about 2 miles off.
Hongkong	36	39½	
Amoy	36	50	
Yangtze:			
Shanghai	Variable.	.....	Usually Shanghai can be reached by vessels of 16 to 21 feet draft at autumn high water neaps and springs, and of 20 to 25 feet at spring high water neaps and springs.
Nankin	16	26	A vessel of 28⅛ feet draft went up to Nankin in 1901.
Kyauchau	Unlimited.	.....	Breakwater harbor constructed, and dredged to 33 feet at low water or 42 feet at high water.
Port Arthur	20	26½	
Chemulpo	36	60	
Nagasaki	Unlimited.	.....	Anchorage in 30 feet (low water) or more, as desired.
Osaka	Unlimited.	.....	A breakwater harbor to have depths of 26 to 28 feet is building.
Kobé	Unlimited.	.....	Roadstead with 36 feet at 1 mile off.
Yokohama	31	35	Depths in harbor, 20 to 30 feet at low water. Anchor outside breakwater in any depth.
Yokoska Harbor	60	64	Depths in harbor, 36 to 60 feet at low water.
Sasebo	42	48	Anchor in 36 feet (low water) or less, as desired.
Vladivostok	Unlimited.	.....	Anchor in 36 feet (low water) or more, as desired.

AUSTRALIA.

Adelaide	23	27	To be deepened to 33 feet at low water and 37 feet at high water.
Melbourne	33	35	Channel with unlimited depth at sea entrance. The stated depth is in the South channel dredged cut in the bay.
Sydney	31½	35½	
Newcastle	23	27	
Brisbane	20	25½	
Auckland, N. Z.	31½	40½	
Wellington, N. Z	33	36½	
Hobart, Tasmania	Unlimited.	.....	42 feet at some of the wharves.

TABLE III.—ENTRANCE DEPTHS, 1905, OF PRINCIPAL COMMERCIAL AND NAVAL SEACOAST HARBORS OF THE UNITED STATES.

[Furnished by Brig. Gen. A. Mackenzie, Chief of Engineers, U. S. Army.]

NOTE.—Where not otherwise indicated, the depth given is the least sounding near the axis of the entrance channel of the harbor (irrespective of its width) at the stage of tide specified at the top of the column. In some cases the latest reports do not state the depth but give the maximum draft available.

As the information concerning high water at lowest neap tides, and also concerning depths at a number of localities, was obtained from sources other than official reports of officers of the Corps of Engineers, attention is invited to Table IV, giving data and reduction methods used.

Locality.	Depth at mean low water.	Depth at high water of lowest neap tide.[a]	Remarks.
	Feet.	*Feet.*	
Eastport, Me	[b]11.5	27.0	Depths in Lubec channel. The depth in the northeastern approach exceeds 30 feet at mean low water.
Bar Harbor, Me	20.5	29.7	
Bar Harbor—Harbor of Refuge, Me	42.0	51.2	
Penobscot Bay, Me	66.0	73.7	
Rockland, Me	30.0	37.9	Depths over a limited area behind the breakwater; depths to wharves are considerably less.
Portland, Me	[b]30.0	37.1	
Gosport, N. H. (Isle of Shoals)	33.0	40.0	
Portsmouth, N. H	39.0	46.3	
Sandy Bay, Mass	33.0	40.7	Depths in a narrow channel at southern end of breakwater; depths behind breakwater and at northern entrance exceed 45 feet at mean low water.
Boston, Mass	[b]27.0	34.9	An entrance depth of 30 feet at mean low water is available through Broad Sound to President Roads near Fort Independence; operations are in progress to provide a channel 35 feet deep at mean low water. Contracts for dredging call for completion December 31, 1907.
Provincetown, Mass	48.0	55.6	Depths at anchorage.
New Bedford, Mass	[b]18.0	20.9	
Fall River, Mass	25.0	28.6	
Narragansett Bay:			
Eastern entrance	78.0	80.6	
Western entrance	30.0	32.6	
Providence, R. I	25.0	28.0	
New London, Conn	[b]23.0	24.6	
New Haven, Conn	[b]20.0	25.0	
New York Harbor:			
East River	[b]26.0	30.1	
Southern Entrance	30.0	33.5	Operations are in progress to provide a new entrance through Ambrose Channel, 40 feet deep at mean low water. The available depth in this channel June 30, 1905, was 22 feet at mean low water. The amount of dredging required was estimated as 52,800,000 cubic yards. The total amount excavated to August 31, 1905, was 16,149,557 cubic yards.
Delaware Bay, National Harbor of Refuge.	30.0	33.3	Depth available over a considerable area behind breakwater.
Philadelphia, Pa	[b]22.0	26.4	Operations are in progress to provide a channel 30 feet deep at mean low water at an estimated cost of $5,810,000. June 30, 1905, $3,247,626.90 had been expended.
Baltimore, Md	[b]30.0	30.9	Operations are in progress under a project adopted March 3, 1905, to provide a channel 35 feet deep at mean low water at an estimated cost of $3,465,000. Dredging commenced in July, 1905.
Washington, D. C	[b]19.0	21.3	The existing projects provide for channels 20 feet deep at Washington and 24 feet in the Potomac River below Washington. The dredging of the 24-foot channel below Washington has been completed.
Newport News, Va	[b]30.0	32.0	
Norfolk, Va	[b]28.0	30.1	Channel to navy-yard.
Wilmington, N. C	18.0	19.9	The existing project provides for a mean low water depth of 20 feet. It was estimated at the end of August, 1905, that the channel was 62 per cent completed.
Winyah Bay, S. C	[b]13.0	15.7	Operations are in progress to provide a channel 15 feet deep at mean low water. It was estimated at the end of August, 1905, that about 87 per cent of the work had been done.
Charleston, S. C	26.0	29.9	
Port Royal Naval Station, S. C	19.0	24.0	
Savannah, Ga	19.0	24.2	Operations are in progress to provide a channel 28 feet deep at mean high water (giving about 21.5 feet at mean low water and about 26.7 feet at high water of lowest neap tide), at an estimated cost of $1,777,791. All inside dredging provided for under approved project has been completed. Expenditures to end of August, 1905, $1,180,128.92.

[a] Obtained in all cases by adding range of high water at lowest neap tide to depth at mean low water as given in preceding column.
[b] Maximum draft available at mean low water June 30, 1905.

TABLE III.—ENTRANCE DEPTHS, 1905, OF PRINCIPAL COMMERCIAL AND NAVAL SEACOAST HARBORS OF THE UNITED STATES—Continued.

Locality.	Depth at mean low water.	Depth at high water of lowest mean tide.	Remarks.
	Feet.	*Feet.*	
Brunswick, Ga	18.0	23.1	Operations are in progress to provide a channel 19.3 feet deep at mean low water across the outer bar. June 30, 1905, this work was about 95 per cent completed.
Fernandina, Fla	22.5	27.2	
Jacksonville, Fla	18.0	19.1	Operations are in progress to provide a channel 24 feet deep at mean low water at an estimated cost of $2,109,750. Amount expended at end of August, 1905, $1,565,456.10.
Key West, Fla	25.5	26.1	
Tampa Bay, Fla	a 24.0	26.0	
Pensacola Bay, Fla	a 29.2	29.8	The existing project provides for a channel 30 feet deep, which depth has been obtained. The limiting depth of 29.2 feet June 30, 1905, was occasioned by a short shoal at the outer end of the channel.
Mobile, Ala	a 22.0	22.8	The existing project provides for a channel 23 feet deep.
New Orleans, La	27.0	27.7	Operations in progress to maintain a channel at South Pass, Mississippi River, 26 feet deep through the Pass and a central depth of 30 feet through the jetties at the mouth. During the fiscal year ending June 30, 1905, the available depth at mean low water varied from 27 feet to 29.1 feet (giving 27.7 feet and 29.8 feet at high water of lowest neap tide). Work is in progress to provide a channel through Southwest Pass 35 feet deep at mean low water, at an estimated cost of $6,000,000. Amount expended to June 30, 1905, $1,357,177.44.
Sabine Pass, La	a 23.0	23.3	
Galveston, Tex	27.5	28.1	
San Diego, Cal	a 26.0	27.9	
San Pedro Breakwater Harbor, Cal	37.1	39.1	
Wilmington, Cal	a 19.1	21.1	
San Luis Obispo Breakwater Harbor, Cal.	28.0	29.8	
Port Harford, Cal	23.0	24.8	
San Francisco, Cal	32.8	34.9	
Humholdt Harbor, Cal	25.8	28.4	
Columbia River Entrance	24.8	28.6	
Portland, Oreg	20.0	20.8	
Bellingham Bay, Wash. (approach to New Whatcom and Fairhaven).	(b)	(b)	Approach is deep enough for any draft. Coast Survey Bulletin No. 36 gives 24 feet at the wharves (probably at mean lower low water). The range of tide is about 12 feet.
Everett, Wash	(b)	(b)	Southern part of water front is accessible for vessels of deepest draft.
Seattle, Wash	(b)	(b)	Coast Survey Bulletin No. 36 states that water at wharves is deep enough for any draft.
Port Orchard, Wash	(b)	(b)	Coast Survey Chart 6378 shows depth at entrance of 35 feet and 33.5 feet at Puget Sound Naval Station wharf, mean lower low water.
Tacoma, Wash	(b)	(b)	Coast Survey Bulletin No. 36 states that water at wharves is deep enough for any draft.

a Maximum draft available at mean low water June 30, 1905.

b Standard port for tidal reference is Port Townsend. "Any reference to mean low water will necessarily be purely arbitrary since from the nature of the tides here there is no such thing as mean low water in the sense that this term is generally used." (40523/21.)

TABLE IV.—DATA AND METHODS USED IN OBTAINING ENTRANCE DEPTHS SHOWN IN TABLE III

Locality.	Feet.	Authority.
Eastport, Me.:		
Depth at entrance, mean low water	±11.5	6914/89.
High water of lowest neap tide, 1905 (July 26)	+15.5	
Depth at entrance at high water of lowest neap tide	27.0	
Bar Harbor, Me.:		
Depth at entrance, mean high water	32.0	C. S. Bul. 36, p. 7.
Mean range in tides	11.5	Ann. Rept. Chf. of Engrs., 1904, p. 21.
Depth at entrance, mean low water	20.5	
Ratio of ranges, Bar Harbor and Boston, 1.16	.....	C. S. Tide Tables, 1905, p. 342.
High water at lowest neap tide, Boston, 1905 (July 26), +7.9. $7.9 \times 1.16 =$	9.164	C. S. Tide Tables, 1905, p. 65.
Depth at entrance at high water of lowest neap tide	29.664	

TABLE IV.—DATA AND METHODS USED IN OBTAINING ENTRANCE DEPTHS SHOWN IN TABLE III—Continued.

Locality.	Feet.	Authority.
Bar Harbor—Harbor of Refuge, Me.:		
Depth at entrance, mean low water	42.0	C. S. Chart, 318.
Ratio of ranges, Bar Harbor and Boston, 1.16	.....	C. S. Tide Tables, 1905, p. 342.
High water at lowest neap tide, Boston, 1905 (July 26), +7.9. 7.9 × 1.16 =	9.164	C. S. Tide Tables, 1905, p. 65.
Depth at entrance at high water of lowest neap tide	51.164	
Penobscot Bay, Me.:		
Depth at entrance, mean low water	66.0	C. S. Chart, 104.
Ratio of ranges, Carvers Harbor and Boston, 0.97	.....	C. S. Tide Tables, 1905, p. 342.
High water at lowest neap tide, Boston, 1905 (July 26), +7.9. 7.9 × 0.97	7.663	C. S. Tide Tables, 1905, p. 65.
Depth at entrance at high water of lowest neap tide	73.663	
Rockland, Me.:		
Depth at entrance, mean low water	30.0	C. S. Chart, 320.
Ratio of ranges, Rockland and Boston, 1.00	.....	C. S. Tide Tables, 1905, p. 342.
High water at lowest neap tide, Boston, 1905 (July 26), +7.9. 7.9 × 1.00 =	7.9	C. S. Tide Tables, 1905, p. 65.
Depth at entrance at high water of lowest neap tide	37.9	
Portland, Me.:		
Depth at entrance, mean low water	30.0	6914/89.
High water at lowest neap tide, 1905 (July 26)	+ 7.1	C. S. Tide Tables, 1905, p. 61.
Depth at entrance at high water of lowest neap tide	37.1	
Gosport, N. H.:		
Depth at entrance, mean low water	33.0	C. S. Chart, 330.
Ratio of ranges, Isle of Shoals Light and Portland, 0.98	.....	C. S. Tide Tables, 1905, p. 344.
High water at lowest neap tide, Portland, 1905 (July 26), +7.1. 7.1 × 0.98 =	6.958	C. S. Tide Tables, 1905, p. 61.
Depth at entrance at high water of lowest neap tide	39.958	
Portsmouth, N. H.:		
Depth at entrance, mean low water	39.0	C. S. Chart, 329.
Ratio of ranges, Portsmouth and Portland, 1.03	.....	C. S. Tide Tables, 1905, p. 344.
High water at lowest neap tide, Portland, 1905 (July 26), +7.1. 7.1 × 0.98 =	7.313	C. S. Tide Tables, 1905, p. 61.
Depth at entrance at high water of lowest neap tide	46.313	
Sandy Bay, Mass.:		
Depth at entrance; mean low water	33.0	16129/113.
Ratio of ranges, Rockport and Boston, 0.97	.....	C. S. Tide Tables, 1905, p. 344.
High water at lowest neap tide, Boston, 1905 (July 26), +7.9. 7.9 × 0.97 =	7.663	C. S. Tide Tables, 1905, p. 65.
Depth at entrance at high water of lowest neap tide	40.663	
Boston, Mass.:		
Depth at entrance, mean low water	27.0	6864/193.
High water at lowest neap tide, 1905 (July 26)	+ 7.9	C. S. Tide Tables, 1905, p. 65.
Depth at entrance at high water of lowest neap tide	34.9	
Provincetown, Mass.:		
Depth at entrance, mean low water	48.0	C. S. Chart, 341.
Ratio of ranges, Provincetown and Boston, 0.96	.....	C. S. Tide Tables, 1905, p. 344.
High water at lowest neap tide, Boston, 1905 (July 26), +7.9. 7.9 × 0.96 =	7.584	C. S. Tide Tables, 1905, p. 65.
Depth at entrance at high water of lowest neap tide	65.584	
New Bedford, Mass.:		
Depth at entrance, mean low water	18.0	7025/176.
Ratio of ranges, New Bedford and Newport, 1.2	.....	C. S. Tide Tables, 1905, p. 346.
High water at lowest neap tide, Newport, 1905 (August 23), +2.4. 2.4 × 1.2 =	2.88	C. S. Tide Tables, 1905, p. 69.
Depth at entrance at high water of lowest neap tide	20.88	
Fall River, Mass.:		
Depth at entrance, mean low water	25.0	7025/176.
Ratio of ranges, Fall River and Sandy Hook, 1.04	.....	C. S. Tide Tables, 1905, p. 346.
High water at lowest neap tide, Sandy Hook, 1905 (July 25), +3.5. 3.5 × 1.04 =	3.64	C. S. Tide Tables, 1905, p. 85.
Depth at entrance at high water of lowest neap tide	28.64	
Narragansett Bay (Eastern Entrance):		
Depth at entrance, mean low water	78.0	C. S. Chart, 353.
Ratio of ranges, Beavertail Light and Newport, 1.09	.....	C. S. Tide Tables, 1905, p. 346.
High water at lowest neap tide, Newport, 1905 (August 23), +2.4. 2.4 × 1.09 =	2.616	C. S. Tide Tables, 1905, p. 69.
Depth at entrance at high water of lowest neap tide	80.616	

TABLE IV.—DATA AND METHODS USED IN OBTAINING ENTRANCE DEPTHS SHOWN IN TABLE III—Continued.

Locality.	Feet.	Authority.
Narragansett Bay (Western Entrance):		
Depth at entrance, mean low water	30.0	C. S. Chart, 353.
Ratio of ranges, Beavertail Light and Newport, 1.09		C. S. Tide Tables, 1905, p. 346.
High water at lowest neap tide, Newport, 1905 (August 23), +2.4. 2.4×1.09=	2.616	C. S. Tide Tables, 1905, p. 69.
Depth at entrance at high water of lowest neap tide[a]	32.616	
New London, Conn.:		
Depth at entrance, mean low water	23.0	21891/80.
High water at lowest neap tide, 1905 (January 15)	+1.6	C. S. Tide Tables, 1905, p. 71.
Depth at entrance at high water of lowest neap tide[b]	24.6	
Providence, R. I.:		
Depth in channel at mean low water	25.0	7025/176.
Ratio of ranges, Providence and Newport, 1.27		C. S. Tide Tables, 1905, p. 346.
High water at lowest neap tide, Newport, 1905 (August 23), +2.4. 2.4×1.27=	3.048	C. S. Tide Tables, 1905, p. 69.
Depth in channel at high water of lowest neap tide	28.048	
New Haven, Conn.:		
Maximum draft which could be carried through main channel June 30, 1905, mean low water	20.0	21891/80.
Ratio of ranges, New Haven and Willets Point, 0.83		C. S. Tide Tables, 1905, p. 348.
High water at lowest neap tide, Willets Point, 1905 (July 26), +6.0. 6.0×0.83=	4.98	C. S. Tide Tables, 1905, p. 77.
Depth in channel at high water of lowest neap tide	24.98	
New York Harbor (East River):		
Depth at mean low water	26.0	
Ratio of ranges, Hallets Point Light, Hell Gate, and New York, 1.2		C. S. Tide Tables, 1905, p. 348.
High water at lowest neap tide, New York, 1905 (July 26), +3.4. 3.4×1.2=	4.08	C. S. Tide Tables, 1905, p. 81.
Depth at high water of lowest neap tide	30.08	
New York Harbor (Southern Entrance):		
Depth at entrance, mean low water	30.0	51984/18.
High water at lowest neap tide, Sandy Hook, 1905 (July 26)	+3.5	C. S. Tide Tables, 1905, p. 85.
Depth at entrance at high water of lowest neap tide	33.5	
Delaware Bay (National Harbor of Refuge):		
Depth at mean low water	30.0	C. S. Chart, 379
Ratio of ranges, Delaware Breakwater and Sandy Hook, 0.94		C. S. Tide Tables, 1905, p. 354.
High water at lowest neap tide, Sandy Hook, 1905 (July 26), +3.5. 3.5×0.94=	3.29	C. S. Tide Tables, 1905, p. 85.
Depth at high water of lowest neap tide	33.29	
Delaware River, to Philadelphia:		
Greatest draft available June 30, 1905, at mean low water, about	22.0	21892/133.
High water at Philadelphia at lowest neap tide, 1905 (January 30)	4.4	C. S. Tide Tables, 1905, p. 87.
Depth at high water of lowest neap tide	26.4	
Baltimore, Md.:		
Available draft at mean low water, June 30, 1905	30.0	6927/88.
High water at lowest neap tide, 1905 (July 26)	.9	C. S. Tide Tables, 1905, p. 101.
Depth at high water of lowest neap tide	30.9	
Washington, D. C.:		
Available draft in Potomac River channels June 30, 1905, at mean low water	19.0	6698/72.
High water at lowest neap tide, Washington, 1905 (June 27)	2.3	C. S. Tide Tables, 1905, p. 96.
Depth at high water of lowest neap tide	21.3	
Newport News, Va.:		
Available draft, June 30, 1905, at mean low water	30.0	47655/40.
Ratio of ranges, Newport News and Old Point Comfort, 1.04		C. S. Tide Tables, 1905, p. 356.
High water at lowest neap tide, Old Point Comfort, 1905 (July 25), 1.9. 1.9×1.04=	1.976	C. S. Tide Tables, 1905, p. 93.
Depth at high water of lowest neap tide	31.976	
Norfolk, Va.:		
Draft available to United States Navy-Yard, June 30, 1905, at mean low water	28.0	47655/40.
Ratio of ranges, Norfolk Navy-Yard and Old Point Comfort, 1.08		C. S. Tide Tables, 1905, p. 356.
High water at lowest neap tide, Old Point Comfort, 1905 (July 25), 1.9. 1.9×1.08=	2.052	C. S. Tide Tables, 1905, p. 93.
Depth at high water of lowest neap tide	30.052	

[a] See Providence, R. I.

[b] See New Haven, Conn.

TABLE IV.—DATA AND METHODS USED IN OBTAINING ENTRANCE DEPTHS SHOWN IN TABLE III—Continued.

Locality.	Feet.	Authority.
Wilmington, N. C.:		
Draft available in Cape Fear River and over ocean bar, mean low water	18.0	52095/15.
High water at lowest neap tide, 1905 (January 20)	1.9	C. S. Tide Tables, 1905, p. 103.
Depth at high water of lowest neap tide	19.9	
Winyah Bay, S. C.:		
Maximum draft that can be carried from Georgetown to the sea at mean low water	13.0	47834/36.
Ratio of ranges, Georgetown and Charleston, 0.69		C. S. Tide Tables, 1905, p. 362.
High water at lowest neap tide, Charleston, 1905 (July 26), 3.9. 3.9×0.69=	2.691	C. S. Tide Tables, 1905, p. 109.
Depth at high water of lowest neap tide	15.691	
Charleston, S. C.:		
Depth at entrance at mean low water	26.0	47834/36.
High water at lowest neap tide, 1905 (July 26)	3.9	C. S. Tide Tables, 1905, p. 109.
Depth at entrance at high water of lowest neap tide	29.9	
Port Royal (Naval Station), S. C.:		
Depth on Port Royal bar	19.0	C. S. Bul. 36, p. 48.
Ratio of ranges, Hilton Head and Savannah, 0.93		C. S. Tide Tables, 1905, p. 362.
High water at lowest neap tide, Savannah, 1905 (July 26), 5.4. 5.4×0.93=	5.022	C. S. Tide Tables, 1905, p. 115.
Depth at entrance at high water of lowest neap tide	24.022	
Savannah, Ga.:		
Controlling depth, June 30, 1905, at mean low water	19.0	6829/146.
Ratio of ranges, Savannah and Savannah Entrance, 0.96		C. S. Tide Tables, 1905, p. 362.
High water at lowest neap tide, Savannah Entrance, 1905 (July 26), 5.4. 5.4×0.96=	5.184	C. S. Tide Tables, 1905, p. 113.
Depth at entrance at high water of lowest neap tide	24.184	
Brunswick, Ga.:		
Controlling depth, June 30, 1905, at mean low water	18.0	6829/146.
Ratio of ranges, St. Simon Light and Savannah, 0.95		C. S. Tide Tables, 1905, p. 364.
High water at lowest neap tide, Savannah, 1905 (July 26), 5.4. 5.4×0.95=	5.130	C. S. Tide Tables, 1905, p. 113.
Depth at entrance at high water of lowest neap tide	23.130	
Fernandina, Fla.:		
Controlling depth at entrance to Cumberland Sound, June 30, 1905, at mean low water	22.5	6829/146.
Ratio of ranges, Fernandina and Fort Clinch, 0.98		C. S. Tide Tables, 1905, p. 364.
High water at lowest neap tide, Fernandina, 1905 (July 25), 4.8. 4.8×0.98=	4.704	C. S. Tide Tables, 1905, p. 117.
Depth at entrance at high water of lowest neap tide	27.204	
Jacksonville, Fla.:		
Maximum draft available June 30, 1905, at mean low water	18.0	47892/54.
Ratio of ranges, Reddie Point and Old Point Comfort, 0.56		C. S. Tide Tables, 1905, p. 364.
High water at lowest neap tide, Old Point Comfort, 1905 (July 25), 1.9. 1.9×0.56=	1.064	C. S. Tide Tables, 1905, p. 93.
Depth at entrance at high water of lowest neap tide	19.064	
Key West, Fla.:		
Depth at entrance, mean low water	25.5	C. S. Bul. 36, p. 53.
High water at lowest neap tide, 1905 (February 13)	.6	C. S. Tide Tables, 1905, p. 119.
Depth at entrance at high water of lowest neap tide	26.1	
Tampa Bay, Fla.:		
Depth at entrance, mean low water, June 30, 1905	24.0	47892/54.
Ratio of ranges, Tampa and Halifax, 0.51		C. S. Tide Tables, 1905, p. 366.
High water at lowest neap tide, Halifax, 1905 (February 28), 3.9. 3.9×0.51=	1.989	C. S. Tide Tables, 1905, p. 51.
Depth at entrance at high water of lowest neap tide	25.989	
Pensacola, Fla.:		
Maximum draft available June 30, 1905, at mean low water	29.2	47908/29.
Ratio of ranges, Fort Pickens and Galveston, 1.07		C. S. Tide Tables, 1905, p. 366.
High water at lowest neap tide, Galveston, 1905 (January 12), 0.6. 0.6×1.07=	.642	C. S. Tide Tables, 1905, p. 123.
Depth at entrance at high water of lowest neap tide	29.842	
Mobile, Ala.:		
Minimum low water depth, June 30, 1905, about	22.0	21890/61.
Ratio of ranges, Mobile and Galveston, 1.40		C. S. Tide Tables, 1905, p. 366.
High water at lowest neap tide, Galveston, 1905 (January 12), 0.6. 0.6×1.40=	.840	C. S. Tide Tables, 1905, p. 123.
Depth at entrance at high water of lowest neap tide	22.840	

TABLE IV.—DATA AND METHODS USED IN OBTAINING ENTRANCE DEPTHS SHOWN IN TABLE III—Continued.

Locality.	Feet.	Authority.
New Orleans, La.:		
Minimum depth, mean low water, South Pass	27.0	Ann. Repts. Chf. of Engrs.
Ratio of ranges, Port Eads and Galveston, 1.13		C. S. Tide Tables, 1905, p. 366.
High water at lowest neap tide, Galveston, 1905 (January 12), 0.6. 0.6 × 1.13 =	.678	C. S. Tide Tables, 1905, p. 123.
Depth in South Pass at high water of lowest neap tide	27.678	
Sabine Pass, La.:		
Available depth in jetty channel at mean low Gulf level	23.0	55971/4.
Ratio of ranges, Sabine Pass Light and Key West, 0.58		C. S. Tide Tables, 1905, p. 366.
High water at lowest neap tide, Key West, 1905 (February 13), 0.6. 0.6 × 0.58 =	.348	C. S. Tide Tables, 1905, p. 119.
Depth in jetty channel at high water of lowest neap tide	23.348	
Galveston, Tex.:		
Ruling depth on outer bars, June 30, 1905	27.5	43744/38.
High water at lowest neap tide, 1905 (January 12)	.6	C. S. Tide Tables, 1905, p. 123.
Depth on outer bars at high water of lowest neap tide	28.1	
San Diego, Cal.:		
Maximum draft available, June 30, 1905, at mean lower low water	25.0	27644/55.
High water at lowest neap tide, 1905 (July 25)	+ 2.9	C. S. Tide Tables, 1905, p. 145.
Depth at entrance at high water of lowest neap tide	27.9	
Mean height of all low waters above plane of mean lower low water	1.0	C. S. Chart, 5106.
Maximum draft available, June 30, 1905, at mean lower low water	25.0	
Maximum draft available at mean low water taken as	26.0	
San Pedro Breakwater Harbor, Cal.:		
A considerable area behind the breakwater afford-, at mean lower low water, a depth exceeding	36.0	C. S. Chart, 5100 and 1808/25.
Ratio of ranges, San Pedro and San Diego, 1.07		C. S. Tide Tables, 1905, p. 380.
High water at lowest neap tide, San Diego, 1905 (July 25), +2.9. 2.9 × 1.07 =	3.103	C. S. Tide Tables, 1905, p. 145.
Depth behind breakwater at high water of lowest neap tide	39.103	
Mean height of all low waters above plane of mean lower low water at San Diego, 1.0. 1.0 × 1.07 = figure taken as difference between planes of mean lower low and mean low water	1.07	C. S. Chart, 5106.
Depth at mean lower low water	36.0	
Depth at mean low water taken as	37.07	
Wilmington Harbor, Cal.:		
Maximum draft which could be carried into inner harbor at mean lower low water, June 30, 1905	18.0	27644/55.
Add correction as obtained for San Pedro Breakwater Harbor	3.103	
Depth at inner harbor at high water of lowest neap tide	21.103	
Depth at mean low water, obtained as for San Pedro Breakwater Harbor, taken as	19.107	
San Luis Obispo Breakwater Harbor, Cal.:		
Partially protected area has available depth at low water of 21 feet to 27 feet	a 27.0	27644/55.
Ratio of ranges, San Luis Obispo and San Diego, 0.97		C. S. Tide Tables, 1905, p. 382.
High water at lowest neap tide, San Diego, 1905 (July 25), +2.9. 2.9 × 0.97 =	2.813	C. S. Tide Tables, 1905, p. 145.
Depth in partially protected area at high water of lowest neap tide	29.813	
Mean height of all low waters above plane of mean lower low water at San Diego, 1.0. 1.0 × 0.97 = figure taken as difference between planes of mean lower low and mean low water	.97	C. S. Chart, 5106.
Available depth	a 27.0	
Depth at mean low water taken as	27.97	
Port Harford, Cal.:		
Depth at wharf (mean lower low water?)	22.0	27644/55.
Add correction as obtained for San Luis Obispo	2.813	
Depth at wharf at high water of lowest neap tide taken as	24.813	
Difference between planes of mean lower low and mean low water, as obtained for San Luis Obispo	.97	
Depth at wharf	22.0	
Depth at wharf at mean low water taken as	22.97	

a Assumed to mean lower low water.

TABLE IV.—DATA AND METHODS USED IN OBTAINING ENTRANCE DEPTHS SHOWN IN TABLE III—Continued.

Locality.	Feet.	Authority.
San Francisco, Cal.:		
Depth on bar at mean lower low water	31.5	C. S. Chart, 5532.
High water at lowest neap tide, 1905 (January 13)	+3.4	C. S. Tide Tables, 1905, p. 147.
Depth on bar at high water of lowest neap tide	34.9	
Mean height of all low waters above plane of mean lower low water	1.3	C. S. Chart, 5532.
Depth on bar, mean lower low water	31.5	
Depth on bar at mean low water taken as	32.8	
Humboldt Harbor, Cal.:		
Depth at entrance, extreme low water	24.0	7042/150.
Difference between extreme lower low water and mean lower low water	.75	C. S. Bul. 36, p. 67.
Depth at mean lower low water taken as	24.75	
Ratio of ranges, Humboldt Bay bar and Astoria, 0.68		C. S. Tide Tables, 1905, p. 384.
High water at lowest neap tide, Astoria, 1905 (July 26), + 5.3. $5.3 \times 0.68 =$	3.604	C. S. Tide Tables, 1905, p. 153.
Depth at entrance at high water of lowest neap tide	28.354	
Mean height of all low waters above plane of mean lower low water	1.1	C. S. Chart, 5832.
Depth at mean lower low water taken as	24.75	
Depth on bar at mean low water taken as	25.85	
Columbia River Entrance:		
Least depth on bar between the channel buoys, June, 1905, mean lower low water	23.5	36123/124.
Ratio of ranges, Columbia River bar and Astoria, 0.97		C. S. Tide Tables, 1905, p. 384.
High water at lowest neap tide, Astoria, 1905 (July 26), + 5.3. $5.3 \times 0.97 =$	5.141	C. S. Tide Tables, 1905, p. 153.
Depth on bar between channel buoys at high water of lowest neap tide	28.641	
Average height of all low waters above the plane of mean lower low water	1.3	C. S. Chart, 6140.
Least depth on bar between channel buoys, June 30, 1905	23.5	
Depth on bar at mean low water taken as	24.8	
Portland, Oreg.:		
Ruling depth between Portland and the sea at low water, June 30, 1905	20.0	36123/119.
Mean height of all low waters above plane of mean lower low water at Fales Landing	.7	C. S. Chart, 6145.
Depth at mean lower low water taken as	19.3	
Ratio of ranges, St. Helens bar and San Diego, 0.52		C. S. Tide Tables, 1905, p. 386.
High water at lowest neap tide, San Diego, 1905 (July 25), + 2.9. $2.9 \times 0.52 =$	1.508	C. S. Tide Tables, 1905, p. 145.
Depth at high water of lowest neap tide taken as	20.808	

Appendix I.

THE GATUN DAM.[a]

By C. D. Ward,
Member American Society of Civil Engineers.

[Reprinted from Transactions, Vol. LIII, 1904, p. 36.]

In a paper[b] entitled "Inter-Oceanic Canal Projects," by A. G. Menocal, member American Society of Civil Engineers, it is stated that the Government commission appointed in 1875 reported, as to a canal with locks from Colon to Panama, as follows:

> The river (Chagres) is proposed to be crossed by means of an aqueduct having twelve spans of 90 feet each (1,900 feet extreme length), 65 feet wide, and 26 feet deep.

In discussing this paper,[c] the late Ashbel Welch, past president, American Society of Civil Engineers, a thorough and noted canal engineer in his day, said:

> The first thought of an American canal and river engineer, on looking at M. de Lesseps's raised map, is to convert the valley of the lower Chagres into an artificial lake, some 20 miles long, by a dam across the valley at or near the point where the proposed canal strikes it a few miles from Colon, such as was advocated by Mr. C. D. Ward.

The site proposed for this dam was at Gatun, 7.5 miles from deep water at Colon, the end of the canal. But, as is well known, the use of locks was not to be thought of under M. de Lesseps's domination, and a sea-level canal was commenced in 1883.

In 1887 it was at last decided that locks would have to be used, and from that time to the present, various locations and elevations for the necessary locks have been suggested, and different sites for the great dam selected.

The New Panama Canal Company and the Isthmian Canal Commission of 1899, the latest authorities, agree in locating the dam near Bohio, 16.5 miles from deep water at Colon, or 9 miles farther upstream than Gatun, the location suggested by Mr. Welch in 1880.

Furthermore, the Isthmian Canal Commission says in its report that "no location suitable for a dam exists on the Chagres River below Bohio.[d]

The late George S. Morison, past president, American Society of Civil Engineers, a member of the Isthmian Canal Commission, commenced his paper on the Bohio dam, which was presented to this society on March 5, 1902,[e] with this sentence:

> All engineers who have examined the route of the Panama Canal agree that the neighborhood of Bohio is the only available location for the dam by which the summit level must be maintained.

Neither of these authorities mentions or gives any consideration to the project of a dam at Gatun, nor even condemns it; nor is the writer aware that any soundings or other examinations, looking to a dam at that point, have ever been made.

As this question may be worthy of more consideration than it seems to have received, some of its advantages may be stated. The canal, as proposed by the latest authority, the Isthmian Canal Commission, may be briefly described as follows: From deep water in Colon Harbor to the Bohio locks, the Atlantic maritime level, cut mostly through the low flat valley of the Chagres, will be 16.81 miles long. The two Bohio locks, with a lift of 45 feet each, reach the Bohio Lake, formed by the Bohio dam, with a maximum elevation of 90 feet above tide in Colon Harbor and an area of 38.5 square miles. The summit level thus attained extends through the Culebra cut. The distance from the Bohio locks to the Culebra cut is 13.61 miles, and from thence through the Culebra cut to the Pedro Miguel locks at the farther end of the level the distance is 7.91

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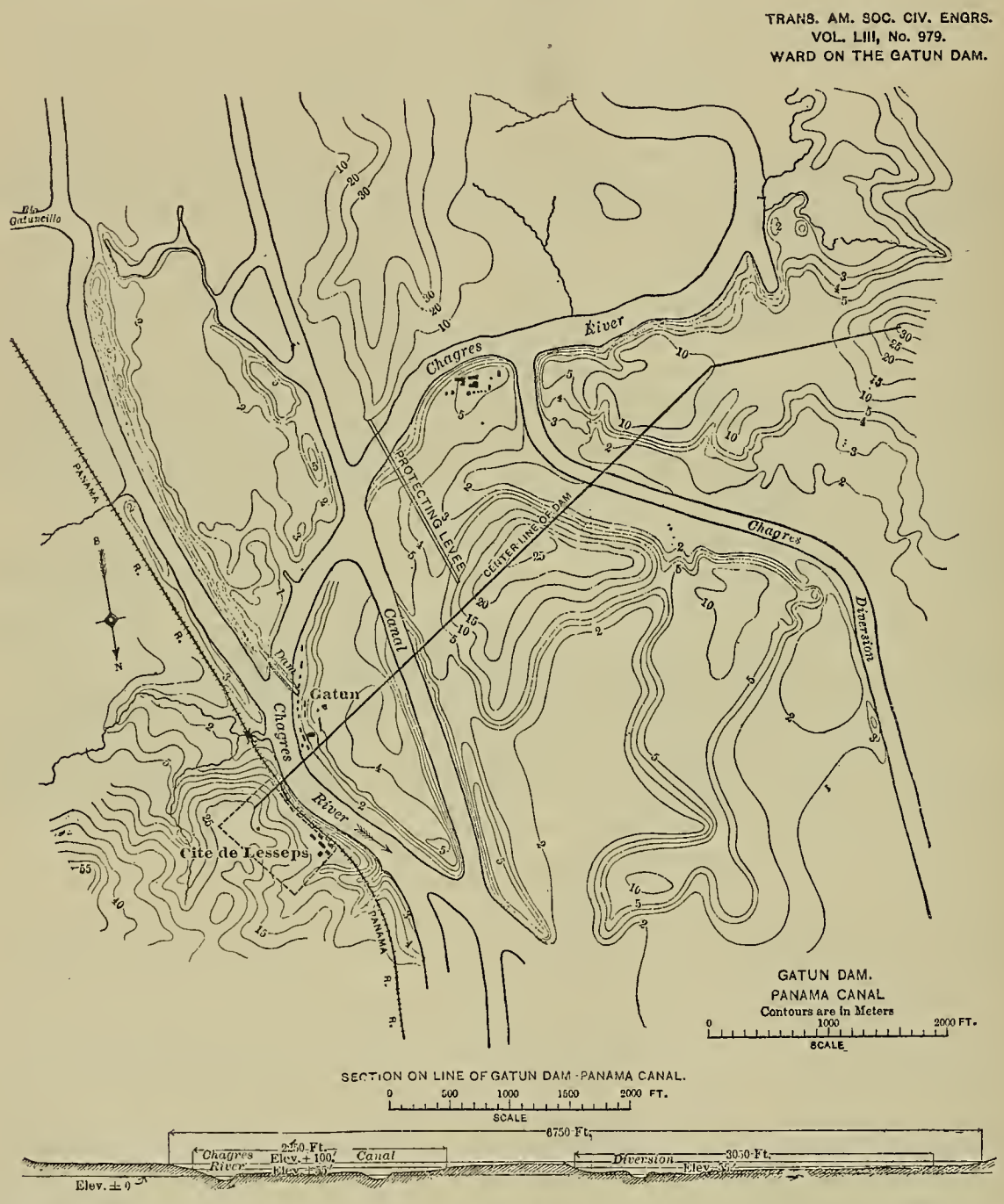
[a] Presented at the meeting of May 18, 1904.
[b] Transactions, Am. Soc. C. E., 1879, Vol. VIII, p. 311.
[c] Transactions, Am. Soc. C. E., 1880, Vol. IX, p. 148.
[d] Report of the Isthmian Canal Commission, 1899–1901, p. 90.
[e] Transactions, Am. Soc. C. E., Vol. XLVIII, p. 235.

miles. The maximum combined fall of these two locks is 62 feet. From Pedro Miguel locks a level of 1.33 miles extends to Miraflores lock, which has a maximum fall of 38 feet to mean low tide in Panama Harbor. For a distance of 4.12 miles beyond this lock the canal extends, through the low swampy country in which the Rio Grande flows, to a point known as La Boca, on the



edge of Panama Bay. A dredged channel extends from this point 4.41 miles to the 6-fathom line in Panama Bay.

Allowing 0.90 mile for the various locks, the total length of canal is 49.09 miles.

As to the suggested dam at Gatun, the New Panama Canal Company has made a contour map of the region where the dam would probably be located, if at all. This map is reproduced, and from it the writer has constructed a section on the proposed center line of the dam. This

section indicates the surface of the ground, but, unfortunately, does not show the rock or other solid foundation. If a dam were built here, impounding the water to an elevation of 90 feet, then, of course, the Bohio dam and the locks and spillway would be omitted, and locks would be built at Gatun.

The length of the dam would be 6,750 feet, while the length of the Bohio dam is 2,546 feet. The area of the section is nearly three times that at Bohio; therefore it might not be out of the way, for the present, to say that the cost of the Gatun dam would possibly be three times that estimated for the Bohio dam, or $19,108,920. At present, there seems to be no reason to think that the locks would cost more at one place than at the other, but the spillway should be somewhat longer, and might cost more. There may be a question whether the hills to the west of Gatun are high enough to contain the Gatun Lake at an elevation of 90 feet, but the raised map made by the New Panama Canal Company, a reproduction of which is to be seen at Columbia University, indicates sufficiently high ground. The lake would extend far up the valley of the Rio Gatun on the east and the Rio Trinidad on the west, and submerge the Chagres Valley for 9 miles, including the Aqua Clara, Peña Blanca, Vino Tinto, and Bruja swamps, cover 20 or 30 square miles of swampy land, and thus improve the healthfulness of the country. This lake area added to the 38.5 square miles of the Bohio Lake would be a benefit in every way and would render the Alhajuela dam on the upper Chagres unnecessary. Between Gatun and Bohio the excavation of the sea-level canal, the Peña Blanca Swamp outlet to Aqua Clara Swamp, the Chagres diversion from Aqua Clara Swamp to near Gatun, and the diversion of the Rio Gatun would become unnecessary and their cost would be saved. These items amount to $14,635,604, a sum large enough to pay the assumed extra cost of the Gatun dam and leave about $2,000,000 to pay for changing the line of the Panama Railroad and the possible additional cost of the spillway. If these assumptions should prove practicable, the result would be a better and safer canal, shorter time of transit, and more healthy conditions, all at no greater cost, and with lower maintenance charges.

If a dam at Gatun with an elevation of 90 feet were found inadvisable, one of 45 feet elevation might be built and the Bohio dam and lake retained. Then the lower Bohio lock would be omitted and established at Gatun and a spillway built there also. The cost of the 45-foot Gatun dam might be assumed at $12,000,000, about twice the estimated cost of the Bohio dam. Its length would be 5,150 feet. The head on the Bohio dam would be reduced from 90 to 45 feet, and the danger from seepage greatly reduced.

It seems quite possible that with this 45-foot dam the total cost of the canal would be reduced a few million dollars below the figure named in the report of the Isthmian Canal Commission.

Turning from the Colon end of the canal to the Panama end, it appears that from the Miraflores locks to La Boca, a distance of 4.12 miles, the canal is to be excavated at sea level through a low swampy country, with occasional rock, at a cost of $10,963,458. It is suggested, as a plan worth consideration, that this lock be located at La Boca, that a dam and spillway be built there, and that the 4.12 miles of swamp be thus flooded, thus affording better and safer navigation than would be had in a narrow channel. The main dam would probably be a mile long, with two or three shorter dams, and might cost no more than the excavation of the 4.12 miles of canal that would be saved. The malarial swamps would be submerged, also. With the 20-foot rise and fall of tide at Panama, the inrush and outrush of the water in that 4.12 miles of sea-level canal might incommode navigation. All this would be done away with if the last lock was placed at La Boca.

Recurring to the suggested 45-foot Gatun dam, with its large lake, the plan of reducing the elevation of the summit level from 90 to 45 feet may be briefly considered. This elevation is suggested, as 45 feet seems to be the maximum permissible lift for a lock.

The elevation of 90 feet for the Bohio dam seems to have been selected with reference to flood control and in order that the resulting lake should have an area large enough to supply water for lockage, seepage, and evaporation during the dry months, without too great a change in the elevation of the surface of the lake.

The 45-foot dam at Gatun would be so much farther downstream that it might be expected to form as large a lake as the 90-foot Bohio dam and perform all the functions of the Bohio Lake.

With one lock at Gatun and one at La Boca, each of 45 feet lift, the lockage would be reduced to a minimum, and rapidity and safety of transit would be secured. The cost of the modified project might be as follows:

Colon entrance and harbor	$8,057,707
Colon Harbor to Gatun	942,293
Gatun dam, spillway, and locks	19,000,000
Lake Gatun, upper end to Obispo	20,000,000
Obispo gates	295,434
Culebra section	63,500,000
La Boca dam, locks, and spillway	15,000,000
La Boca to deep water	1,464,513
Panama Railroad diversion	1,000,000
	129,259,947
Add 20 per cent	25,851,989
Total	155,111,936

The estimate made by the Isthmian Canal Commission, with the summit level at 90 feet, was $144,233,358.

The suggestions of twenty-four years ago have thus been elaborated and presented in this short paper in the hope that, in the discussion, it will appear whether examinations have been made, by any of the various commissions or other, as to the practicability of a dam at Gatun, and, if so, with what result.

If it should appear that such examinations have not been made, it is hoped that this paper will induce those in authority to make such examinations before deciding upon the final plans for the Panama Canal.

Appendix J.

HEARINGS BEFORE THE BOARD AND NOTES OF MR. JOHN F. WALLACE.

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STATEMENT OF MR. JOHN F. STEVENS.

At 9.40 a. m. Mr. Stevens appeared before the Board.

The Chairman. Mr. Stevens, will you kindly tell us how long you have been connected with the canal enterprise as chief engineer?

Mr. Stevens. Nominally since the 1st of July; I have been on the ground since the 26th.

The Chairman. The Board has indicated to the Chairman of the Commission a certain general line on which it was thought that questions should be asked, and perhaps you have seen the resolution which the Board adopted a few days ago and sent to the Chairman.

Mr. Stevens. I saw it a couple of days ago.

The Chairman. As no type of canal has yet been adopted, and as none can be adopted until this Board reports and action is had thereon, it becomes necessary to assume something for purposes of questions and to elucidate the canal project; first, the practicability of the canal; second, as to the time it will take to build it, and third, as to its cost. This Board in one of its earlier meetings adopted a resolution which declared that the line of canal as generally indicated on the maps from Colon to Panama would be the line on which the canal would be constructed. That does not mean that there might not be radical changes from previously recommended plans, in respect to location, in respect to curves, in respect to locks or dams. Now, as regards the Culebra itself (and when I use the term Culebra I mean that portion between Bas Obispo and Paraiso), from the observations you have made here respecting the stability of the material, the risks of slides, drainage, etc., can you suggest any change in the alignment of the Culebra section to the advantage of the work; I mean flattening of curves, excavating from the side opposite to the Culebra, or changing the axis of the canal—in short, any improvement in the line through the Culebra?

Mr. Stevens. No, sir.

The Chairman. You have had a large experience in the excavation of material and in the transportation of it for engineering works in the United States. In the light of your past experiences and in the light of your observations on the Isthmus since you have been here, what type of excavating machine do you regard as the most advantageous one?

Mr. Stevens. For the Culebra work?

The Chairman. Yes.

Mr. STEVENS. As far as my experience and observation goes, the shovel—steam shovel.

The CHAIRMAN. From your experience in the United States and your experience on the Isthmus, what is the comparative measure of efficiency of a steam shovel there and at the Culebra throughout the year?

Mr. STEVENS. My experience on the Isthmus is not enough to justify me in giving an opinion, General. If you will allow me to explain I will tell you why. I came here practically on thirty-six hours' notice, and on my arrival I found a state of chaos. I have been trying to get an organization that was sufficient to tide over until the type of canal was decided upon. It required a vast amount of work to get the men quartered. I have taken very little time, practically none, for studying the type of canal or the problems involved, first, because I have not had time—it was beyond human power to do it—and second, because I considered that the type would be settled for me, and when that was done I would take up the study of that particular type. I know that it is a very weak thing to say that a man is overworked, but I have had five hours' sleep in the last sixty. I have been kept constantly moving, and as as a matter of fact, there is not one of the salient points that is under discussion here to-day to which I have given a careful examination—not even the Gatun dam site or the Bohio dam site. I merely mention this, for there is a limit to everything.

The CHAIRMAN. Would you like to postpone this hearing until this afternoon?

Mr. STEVENS. No; I want to go ahead.

The CHAIRMAN. We observe that you are preparing dump tracks that have a considerable extension, and this certainly looks to the disposal of spoil. It looks to the transportation of the material taken from the summit cuts and carried to some distance. Now I will ask this question—I will try to make it as broad as possible and hope that you can enlighten us somewhat: Assuming that you have the whole Isthmus of Panama for a dump and the Caribbean Sea and the Panama Bay for a dump, without limit or restriction, except that no material is to be placed so that it can get back into the canal—suppose everything else is at your command, and suppose you have entire free scope as to the accumulation of plant and its installation for taking out 100,000,000 cubic yards from the Culebra divide—this in connection with perhaps an equal amount of excavation from the remainder of the canal, and supposing that your plant is such as you wish in the number of units and their distribution, can you tell us something about when you could get ready for a maximum output, and how much we could rely upon per annum, or how much you think it safe to presume you might accomplish per annum—for this matter of time of construction as laid down in the instructions of the President is very important indeed?

Mr. STEVENS. There are quite a number of things that have got to be determined before any definite answer can be given. First, the proposition has not been worked out in detail. I found after I came here that there had been no systematic examination, no surveys showing the heights of dumps, which is a very important consideration in the disposal of the material in this cut. I made a thorough examination of what I call the long-distance dumps, between Bas Obispo and Bohio. It would seem that wherever they found a place to put some material they established a dump ground. Now, the area that is available, that probably would be practicable, is small. I do not really believe that when you figure the transportation, and figure the difference in the dumps properly laid out in long straight tracks (and no dump ground should be laid out that had not three long straight tracks on it), I do not believe that as far as capacity is concerned that there will ever be over three or four million yards disposed of on one of the sites—I mean alongside of the canal, close to it—for the reason that the dumps are small. They are not well located; they are badly located in regard to their shape and general conditions. That means that the bulk of the material has got to be hauled long distances.

Regarding time—that is a hard question. Theoretically we can say that one unit, under first-class supervision, can do so much; we do not know whether it can do it or not. Theoretically, this mass in the Culebra shown by our soundings and all the data we have, we ought to move offhand, say, 1,000 yards a day per shovel. But it is a totally unknown quantity and it has got to be experimented with before we can tell. All I can say is that we hope to do it. Now, as to the number of units we can use—that is unknown. The cut is not in good shape. It will take a long time to shape it up. The fact is, if the new French company had left two

or three million yards in the cut that they have taken out, it would be a distinct gain. I would prefer to dig the cut with this two or three million yards in there than I would now. All of which means more preliminary work to get in the proper system of tracks. There are three or four systems of tracks which are applicable, but there is not one of those systems which can be applied for at least two or three years to all of that cut. With this class of material, 25 or 30 feet is probably the normal depth to which the shovels will work. Each one of those levels from both sides has got to be considered as a different proposition. To use the homely expression of Josh Billings, "They are like boils, and each one requires a different poultice to bring it to a head." Including the shovels that are under contract, I have arranged for 60. We are at a long distance from the repair points. Perhaps from 15 to 20 per cent of those shovels would be out of service under repair. That would leave me probably 50 shovels—that is all I could get running by June or July next, taking advantage of the presumably dry season which we should have by December, and I think I have figured pretty optimistically about that.

The CHAIRMAN. That is, you would get 50 shovels installed in about ten months?

Mr. STEVENS. I hope to, but as for giving the date that would be an impossibility.

The CHAIRMAN. This Board must report to the Commission and the Secretary of War on the subject of time to open the canal, and we are endeavoring to get data in regard to possible progress and time.

Mr. STEVENS. You know there is such a thing, General, as throwing time away by being in too much of a hurry.

Mr. BURR. I would like to ask, after these 60 shovels have been installed with 15 or 20 per cent out on the average for repairs, about how many more the chief engineer would expect to be installed in order to reach what we might call his maximum working equipment of that class?

Mr. STEVENS. That would depend altogether on how our plans worked out and how well we get along. Of course, it gets right back to the old question of the type of canal. Assuming a lock canal, to which I have given very little study but from the best information I have there is one part it will take years to build—that is the auxiliary works outside the main cutting. Now, you can do a thing quickly at a heavy expense, you can do it a little slower at a reasonable expense, and you can do it very slowly at a heavy expense again. After the type of the canal is settled if there are any of these auxiliary works, that will take five or seven years; if we can save money and do a better job at the Culebra cut, then it would be a proper thing to do it. It is a hard thing to say how fast you will dig out after it has been decided. As I started to say, I have never believed (throwing aside the question of a sea-level canal, which I confess I have not gone into at all) that under the greatest stress we would require on the Isthmus the presence of over 100 excavating machines.

The CHAIRMAN. Throughout the whole length?

Mr. STEVENS. I am talking about the Culebra cut. This brings up another point. We have the eight-hour law, which from our point of view is a very grave misfortune. If we were not subjected to that handicap, and if the exigencies of the case required the auxiliary works to be carried on in harmony with the general plan, night work might be carried on. Yet you will understand that it will take, say, a year and a half to get quarters. We have got to duplicate all those quarters to take care of the additional men. It is a question whether the exigencies would require simply eight hours or whether we would run two shifts. Now, a night shift, as a rule, does not do as much as a day shift, except in mining under ground, and the efficiency of the probable eight-hour night shifts would not be, probably, more than 80 per cent of day work; but then again, if the work was demanded in that time it could be arranged.

Mr. HUNTER. I understand that Mr. Stevens thinks that it will be possible to work 80 shovels between Paraiso and Obispo.

Mr. STEVENS. I said there would be 100 shovels on the Isthmus; 80 per cent would be working at a time. It is only a guess, I can not say positively.

Mr. HUNTER. Eighty shovels.

Mr. STEVENS. I think it can be done. The question of handling the Culebra cut, in view of what I said, and the long haul, is whether you require the material for any auxiliary works or whether the material must be taken away long distances. The question of handling the Culebra

cut is very largely one of transportation, and by transportation I do not mean simply hauling it, I mean disposing of it—getting rid of it. It is going to require the most perfect organization that ever was contemplated; but it is something that we have not got far enough along with yet to give the details. I regard the whole Culebra cut as a soft-rock proposition, because the great part of it has got to be shot. While it is true that a shovel would pick up some of it without blasting, you can do it all much more economically to shoot it. Therefore, when you come to a question of how much an excavator will handle—I do not care whether it is a French machine, English machine, or a steam shovel—if you can keep the cars or the scows or whatever are serving the excavating machines, there is no limit of power of the machines, it is merely the disposal of the material. The French company fell down because they could not dispose of the material. Now we criticise their plant, but that is not fair. They loaded more than they could get rid of. That is perfectly clear to me by the casual examination I have given their excavators and the different spoil banks. They used a heavy grade and a type of car that would not dispose of the material; it had to be cleared by shoveling. At that time it was considered a modern plant. Now I would liken that plant to a modern one as baby carriages to automobiles. This is no reflection on the French, but I can not conceive how they did the work they did with the plant they had.

Mr. BURR. Has the chief engineer, so far as his experience has gone, reached no approximate idea as to the slopes which it would be fair to assume to enable us to estimate the amount of excavation in the Culebra below the upper soft portion; or, to put it definitely, the lower three-fourths of the depth in case a sea-level canal or a less proportionate depth in case of a lock canal?

Mr. STEVENS. As far as I have been able to observe, you can classify the Culebra above as red clay overlying argillaceous schists, with hard igneous trap thrown up through it. A great many borings have been made. It is a mixed conglomerate mass. Sometimes at 100 feet from a boring the conditions may be entirely different. If the material is, as some say, like that seen in the center of the big cutting, then I would consider it a waste of money to dig it out with a 1 to 1 slope. I have had a great deal of experience in handling all sorts of material, heavy and light, and the old formula used to be in such cuttings 1½ to 1. Now, a great many years ago I made up my mind that I was not spending money to the best advantage. I was on the west coast, at Puget Sound, and I formed a theory that in the case of that material which I called hardpan that if I had 20,000 yards to take out of a cut, instead of taking it out with a slope of 1½ on 1, why not widen my base—the cost would be the same—on the theory that in a country where there is a heavy rainfall a material that would stand with steep slopes offered so much less area for rivulets to form; and for a long time either in the soft rock or compact indurated clay I have adopted that policy. If my standard roadbed was 26 feet and I had a 40-foot cut, I probably made the cut 45 feet wide. Occasionally that would fall down; when it did I had plenty of room to remove the material. I believe that when we get back to these slopes at deeper cuttings if the material proves to be what I call homogeneous, that is it does not lie tilted or in layers, and we find a horizontal strata that would stand without question, and under that we find a strata that the air and water would gradually work on—if we find a condition of that kind there is nothing to do but make the slopes so that the soft material under the harder materials will come to a rest, but outside of that if we get hard material it is my honest opinion that it will stand just as well vertically as at any other slope.

The CHAIRMAN. You are going to take off that red and chocolate colored material before going deeper?

Mr. STEVENS. That top stuff will cost more to handle than any material you see in the cut. There is no excavator that will clear that, during the wet season. It means that you must get ready to do all of that work you can in the dry season.

The CHAIRMAN. You expect to keep rivulets out of the cut?

Mr. STEVENS. Not altogether. I expect there are times when you will have to abandon certain parts of the cut. During the storm there yesterday, in a couple of hours probably two inches of water fell. It was a tremendous fall.

Mr. PARSONS. May I ask, Mr. Chairman, that taking Mr. Stevens's statement as he has made it, has he made any computations of quantities in the Culebra cut for the various depths of canal?

Mr. STEVENS. I have not. I have seen estimates of quantities made there. I assume they are taken from cross sections and are therefore correct.

Mr. PARSONS. Referring to the statement you made about a 1 to 1 slope. The soft material at the top would have to be excavated to that slope. The material below that, taking the cut as it is at present, would be wide enough for a high-level canal. There would be just as much of the upper red clay to remove for a high-level as for a deeper one.

Mr. STEVENS. It would be a question of slopes below.

Mr. PARSONS. If we go down 4 on 1 from where we are now, the upper part of the cut is wide enough for a very low canal.

Mr. STEVENS. For making a comparison the only fair way to do is to assume the same slope for every type.

Mr. PARSONS. I would like to know whether Mr. Stevens has any figures.

Mr. STEVENS. I have not. No, sir.

Mr. HUNTER. If we got the cross sections we could make the computation.

Mr. PARSONS. We could make it if Mr. Stevens could give us the cross sections.

Mr. STEVENS. The question of calculation of quantities is simply mechanical; you saw those slope boards set out all through there. The canal has undoubtedly been cross sectioned at sufficient distances apart so that those cross sections could be platted out with the slope desired and calculated. It is simply a matter of calculation.

Mr. BURR. Those slope boards were placed on a basis of slope of 1 to 1?

Mr. STEVENS. I understand so, for a canal 35 feet below low tide.

Mr. PARSONS. Could Mr. Stevens give us two or three cross sections at important parts of the canal?

Mr. STEVENS. You understand, Mr. Parsons, it would be only on the assumption that the material was hard enough to stand. I was merely taking a theoretical case.

Mr. WELCKER. May I suggest that Mr. Stevens give us his opinion on the number of real working days there are on the Isthmus in the wet season.

Mr. STEVENS. You want to know what I consider the number of real working days in a month?

Mr. WELCKER. Yes.

Mr. STEVENS. You can not apply any rule deduced from conditions in the United States to the work here.

Mr. WELCKER. Can not you give any figure?

Mr. STEVENS. Let me explain a little. The only country in the United States that approximates this in the amount of rainfall is the Puget Sound country. You understand they pay no attention to rain up there. It is all white labor, probably the best in the United States, and they go on working whether it rains or shines. It is different here. If there is a cloud across the sky here they start out with an umbrella as well as a cigarette, and if that cloud gets pretty large they scud for safety. I should say that if we got thirty-six hours per week we are doing exceedingly well.

The CHAIRMAN. I happen to know from Mr. Renadin that it was the experience of the Frenchmen that they got nineteen days work in the month on an average through the year.

Mr. STEVENS. That is not far from what I said.

Mr. HARROD. That is exactly what the levee people get in New Orleans.

Mr. RIPLEY. You spoke of taking a year or a year and a half to finish the houses for the employees. You meant simply along the large cut?

Mr. STEVENS. No. I refer to the whole situation. There are a good many odds and ends to repair in housing people. For instance, we have prepared in the last three months something over 200 houses. Some of those houses need thorough repairs, reconstructing the entire building,

or it may be simply putting in a water closet. It would be easy to house a very large number of men here in a year and a half if all materials come along as we expect them to. We have at present on the work under the governor and the chief engineer and the chief of the bureau of supplies something over 13,000 men, white and black. We have brought in about 3,200 the last three months and taken on about 4,000 on the real work, that discrepancy being explained by the force of men I have who go around and put the laborers out of their houses unless they work. Those workmen are all reasonably well taken care of. There are many repairs to be made to the quarters they are occupying.

The CHAIRMAN. Can you indicate a probable maximum force of laborers to be employed?

Mr. STEVENS. I would have to ask you, General, what kind of a canal we are going to build? The sanitation, of course, is the uncertain proposition. There are a great many abandoned camps from here to Obispo, and as those camps are rehabilitated Dr. Gorgas will have to put on a large sanitary force; but I do not think that nominally you can work such a large number of men as they talk about, 30,000 to 75,000. I believe that the effective force, white and black, will never run over 20,000. That depends very largely upon the type of labor we try to put up with. We have different ideas as to the effectiveness of these negroes as compared with good white labor.

The CHAIRMAN. Can you estimate the comparative value of the Jamaicans you have here and the Italians, Poles, or Hungarians on the Pacific coast?

Mr. STEVENS. I could tell you what I say sometimes when I am mad, but that would not be an estimate. I have worked Chinamen and Japanese and was, I think, the first man in the United States who employed Japanese on a railroad to a great extent—that was on the Great Northern Railroad.

The CHAIRMAN. How does the Japanese compare with white labor?

Mr. STEVENS. They are about equal to 60 per cent of the white labor.

The CHAIRMAN. How about Italians?

Mr. STEVENS. Some Italians are very good. If you try to initiate a Japanese to new work it is an utter failure. He is a good deal like a monkey. He will watch you tamp a tie and clean up a ditch; if you do it wrong he will do it wrong. That is the greatest trouble I have ever found with them. One of the worst wrecks I ever had on the Great Northern was because a fireman sent a Jap out to flag a train. He said "you take this flag and flag any train that comes along." The Japanese disappeared around the curve and in a minute on came an engine without any train and a bad wreck resulted. The Jap was called to account and replied, "You said to flag every train; that was only an engine." The Japanese is good labor, but not as good as Chinese.

The CHAIRMAN. If a Jap is worth 60 per cent of the Italian, a Jamaican is worth what per cent?

Mr. STEVENS. About 25; not exceeding that as we are working now. That arises from ordinary causes. One of the main objects I had in bringing in more laborers here was because there was a scarcity of labor and they knew it. If you said anything to them they simply dropped their shovel and hired out somewhere else. If a gang is short now, in twelve hours it is filled up. There is also another reason. Our grade of subforeman is deplorably bad. They do not understand, and a great many do not care to. The labor must be improved.

Mr. BURR. I would like to inquire whether the chief engineer thinks it practicable by a proper design of plant, or protection of plant, to decrease the losing effects of the rainy weather, say, by working under cover?

Mr. STEVENS. I do not think there is. I do not think we could do that. There is only one feature of that that has ever appealed to me, and that comes back again to where we want to use the material. With a reasonable haul to the sea to get rid of land dumps, which take lots of changes of tracks and switching of trains—if we could dump this material into big barges and tow it out beyond all danger of drifting back to the canal, then we could work practically whether it rained or not, because we could get white labor; but of course that question has got to be laid on the shelf until the type of the canal and the use of the material is decided upon. Theoretically I could take 20,000,000 or 25,000,000 cubic yards from the Culebra, put it into

scows near La Boca and take it 10 miles out to sea cheaper than I could put it onto land dumps; but I do not know but that you gentlemen want that 25,000,000 yards for something else.

The CHAIRMAN. Could you suggest some unit of cost of that work?

Mr. STEVENS. Do not ask me that, General.

Mr. HUNTER. He has some notion in his mind.

Mr. STEVENS. No, Mr. Hunter, I will be perfectly frank with you. I have got to feel and find out. I will tell you this much, I have done a great deal of work with the labor carried on my own pay rolls, and it has been supervised by engineers, and I think they are about as intelligent a class as there are. I have also had a vast amount of work on percentage where I had direct control or supervision and price of labor, and I was just as much responsible as though I had been the head contractor. I have also had a large amount done by straight contract. The nearest approach of blasting material, hardpan, with a haul from a half mile to three miles, however, but under most favorable conditions, cost from 50 cents to $1.50 a yard. That is a very wide limit. That is with first-class labor. I have also handled labor under favorable circumstances for disposal and transportation. I have handled that material from the places in the bank and put it where it belonged, widening cuts and filling embankments, at 16 cents and 17 cents a yard. I have also handled 3,000 yards a day to the shovel. I have done that work at other places where it has cost me seven or eight times that amount, and to me it is foolish for anyone to come down here and in a few days make a guess as to the cost of this work.

Mr. STEARNS. Is that not what we have got to do?

Mr. STEVENS. Yes; but I do not consider that I am the one appointed to do that.

Mr. PARSONS. Would Mr. Stevens give us a reasonable figure that we could take into account as one of the elements?

Mr. STEVENS. On any level?

Mr. PARSONS. Any level you like.

Mr. STEVENS. I have no opinion whatever to express about the cost for the low level. I have never had any experience and I doubt if anyone has had any. For a high level my opinion is that the figures of the Commission were plenty low.

The CHAIRMAN. You mean 80 cents?

Mr. STEVENS. I think it was an average of 80 cents, but I would not go on record as approving that figure. I have no well-grounded belief that it would be less.

Mr. HUNTER. Mr. Stevens knows that better than we do.

Mr. STEVENS. Well, I do not know that, though we have all the records here. I have never seen the work.

Mr. HUNTER. Whenever we have seen a train dumped here, there were three or four men to the car to shovel it out.

Mr. STEVENS. A great deal of the cost was due to derailments, and sometimes the gangs were not kept full.

Mr. PARSONS. I think this estimate which Mr. Stevens referred to was in the report of the Commission 1899–1901, in which hard rock was $1.15, soft rock 80 cents, earth 45 cents.

Mr. STEVENS. There are about seven months of the rainy season and five months dry. I would prepare to remove the hard rock in the rainy season, then what is called earth I would remove in the dry season. I mean striking a general average as near as we know what the classification may be.

Mr. PARSONS. Taking the Culebra cut from Obispo to Paraiso, averaging it all through, you would call it a soft-rock proposition?

Mr. STEVENS. What I would call hard trap is not large, therefore to average it right through it is a shooting proposition. Any argillaceous schist is always soft.

Mr. PARSONS. You would not recommend that this Board take less than 80 cents as an average for the Culebra cut?

Mr. STEVENS. No, sir; I would not.

Mr. PARSONS. Would you recommend taking 80 cents?

Mr. STEVENS. I would not want to say, Mr. Parsons.

Mr. BURR. Then, Mr. Chairman, I am afraid that the chief engineer thinks those guesses pretty good.

Mr. STEVENS. I said I thought they were low enough. We might as well admit the fact. We may look wise but we generally have to do a lot of guessing. The average guess of quite a number of men is the best thing you can adopt.

General ABBOT. The actual expense of the new company working here shows that the prices in the Culebra varied from $1 to 67 cents, according to locality.

Mr. STEVENS. I do not know how much money they spent on what we call outside work. I judge they moved somewhere near 5,000,000 yards and spent something like $6,000,000.

General ABBOT. They spent considerable money otherwise.

Mr. PARSONS. Mr. Chairman, Mr. Stevens spoke a moment ago of an average cost of 80 cents, did that include the cost of sanitation?

Mr. STEVENS. I am figuring as a contractor, not taking into account sanitation, administration, and policing. I do not give 80 cents as a figure, I simply say it is as low as I would dare to go and stake my reputation on it.

The CHAIRMAN. One of the questions embraced in the resolution of the Board asked for the total amount of work done by the United States since it took the work.

Mr. STEVENS. I had Mr. Dose bring all the daily and monthly reports and he has them here now, but I think I can give them to you.

The CHAIRMAN. Work was begun on the 26th of April, 1904, by the United States.

Mr. STEVENS. Here is a report that was handed to me this morning. It purports to give the cost as the division engineers kept it; simply the division expenses from January up to and including September.

The CHARMAN. This is the report of September?

Mr. STEVENS. Yes. Amount $730,000. I would like to look that over and get the figures.

The CHAIRMAN. Can not you get from the records the quantities, etc., the same data for the work done from January, 1904, and send it up?

Mr. STEVENS. Yes; I can do that.

The CHAIRMAN. Would that record of cost from the engineers' report be obtainable?

Mr. STEVENS. Yes.

The CHAIRMAN. As to the value of the French plant, Mr. Stevens, some of the apparatus was found useful?

Mr. STEVENS. Most of it was of very little use. I think I can utilize a very large quantity of the rails. I did not think I could when I came here. It is rather an awkward section, very high in proportion to its width, and on work tracks it turns over, but I have ordered from the States material for 5 miles of bridle rods. I am going to take those 5-meter rails and use about four bridle rods per rail, and I believe for our dump tracks that we can use 150 miles of the rails. New rails would probably cost $28 a ton in Pittsburg, and it will save a considerable amount. We are going to try that experiment.

The CHAIRMAN. The dredges at Panama, are they of any value?

Mr. STEVENS. I would rather have Mr. Maltby's opinion than mine. He is a better dredge man. I should say no. We have never been able to get over 2,700 or 3,000 yards a day of ten hours per dredge.

Mr. HUNTER. Have you had large experience in dredging in the United States, Mr. Stevens?

Mr. STEVENS. No, sir; I have not. I have had general supervision of a large amount of dredging, but as to the details of construction of the dredge I would not care to say.

The CHAIRMAN. What type of dredge would you prefer?

Mr. STEVENS. I think a suction dredge is the best dredge in the world. Roughly speaking my idea has been for a big job of dredging that we should cut a narrow channel with a dipper dredge and throw our waste on the bank as far back as we could by the machine. That would be the advance, then follow it up with the big hydraulic dredges and throw the material over this spoil bank.

The CHAIRMAN. Using this spoil as a levee?

Mr. STEVENS. Yes.

The CHAIRMAN. If concrete material is needed, would it come from the Isthmus?

Mr. STEVENS. Yes. But the rock has got to be very carefully selected. There is a great deal of rock that is apparently good for work, but for permanent jobs it is not as abundant as would seem; still it can be obtained.

The CHAIRMAN. Would that rock you are taking away from Obispo be suitable for construction?

Mr. STEVENS. No, sir; I would not use it at all.

The CHAIRMAN. Pedro Miguel rock?

Mr. STEVENS. There is a dike there which is very nice rock.

Mr. HUNTER. Would you use the gravel from the Chagres?

Mr. STEVENS. I do not think there is a large quantity of that gravel, and it is not clean. I would prefer to use the sharply broken trap rock than the gravel.

The CHAIRMAN. You think it may be necessary to quarry rock, especially for dam construction?

Mr. STEVENS. I would not say that, General. I think that I could sort it out.

Mr. BURR. Referring to the gravel, I understood Mr. Stevens to express an opinion that the gravel would not be fit for concrete.

Mr. STEVENS. To my notion it is the wrong shape—pumpkin-seed shape—and if I could get a good clean trap I would prefer it, although, of course, good concrete made out of good gravel makes good work; but all things being equal, I would take the trap.

Mr. STEARNS. I would like to know whether, in speaking of rock with a slope of 1 horizontal to 4 vertical, Mr. Stevens had in mind a sea-level canal or a shallower canal?

Mr. STEVENS. For any depth, provided the material was the same.

Mr. STEARNS. I understood that you assumed homogeneous material?

Mr. STEVENS. Yes.

Mr. STEARNS. Is it likely that homogeneous material will be found at great depth?

Mr. STEVENS. I can not tell you that. The only thing that I have is the same as you gentlemen; I have no X-ray machine.

Mr. STEARNS. The other question was with regard to dumping material, whether you anticipate any great advantage from the use of flat cars and plows for unloading?

Mr. STEVENS. I do, very decidedly. To what extent I can not tell, but I know it will clear the material from the cars.

Mr. STEARNS. Is there great difficulty with curved tracks or tracks that have settled?

Mr. STEVENS. You can not handle transportation on any tracks that are settled. I would consider it a judicious expense to keep the tracks in good shape.

Mr. STEARNS. But I understand the unloading plow does not work satisfactorily on a curve or if the track has settled?

Mr. STEVENS. No. I think it is folly to undertake a job with poor tools.

The CHAIRMAN. The straight tracks on the dumps that you propose to run trains on, must they be ballasted?

Mr. STEVENS. That would depend upon the kind of material to be handled. The tracks do not need to be exceedingly smooth, but they need to be quite strong, and should not have mud on one side and rock on the other. I would not ballast it. That is the reason why I say I would not depend on one dump track on any dump line. I would have several tracks.

The CHAIRMAN. Have you read Mr. Bunau-Varilla's scheme for a dam at Gamboa, and to lock the scows with spoil from Culebra up to the reservoir and to deposit it in the lake above the dam?

Mr. STEVENS. I have glanced at it.

Mr. HUNTER. Would you like to convert the Culebra cut into a large lake and take out the material by dredging?

Mr. STEVENS. I think I could find a better method.

Mr. RANDOLPH. What do you know of the rock through the Culebra cut? Do you regard retaining walls as necessary where waves will wash?

Mr. STEVENS. That gets back again to the question of the kind of rock there. I should say that it would not be safe to omit consideration of that point entirely. It depends on whether you have this system of fat and lean streaks of earth and rock. The water that is displaced by a ship of 35 feet draft and 70 feet beam is forced to rush past the vessel. I do not know of any formula that fits it in a narrow channel. We know that with a properly constructed wall it would not affect the wall. Whether it would affect the natural surface of the rock I do not know. It would be a disaster if it did.

Mr. RANDOLPH. Mr. Chairman, is it in order to ask any question we desire?

The CHAIRMAN. Certainly.

Mr. RANDOLPH. Should it be decided to build earth dams so as to form a lake extending from Ancon and Sosa hills back to Miraflores, could you use the excavation from the Culebra cut in forming those dams at a cost which would be less than making excavations wholly to obtain material for that purpose?

Mr. STEVENS. The only practical way that comparison could be made would be to assume that you would dredge your material. I should say, Mr. Randolph, that it would be very near a stand off with that length of haul, and probably it would depend largely on the height of the dam, because that means lifting with mechanical means from the Culebra material.

Mr. RANDOLPH. Assuming that this dam is at plus 65?

Mr. STEVENS. Probably the cheapest way to handle material from the great Culebra cut would be to bring it down and pump it up to the dam; but that again brings in the proposition of the immense amount of rock which can not be handled in that manner, so that it would be necessary to run out directly with trains on the dump.

Mr. RANDOLPH. Would the disposition in these dams tend to delay the progress of the Culebra work?

Mr. STEVENS. No, sir; it would not, because we would adapt ourselves.

Mr. RANDOLPH. Would it be necessary to have independent tracks for this long haul, or could the existing tracks of the Panama road be used without crippling the regular traffic on that road?

Mr. STEVENS. It is necessary to have additional tracks in any case. In the scheme that I have spoken of, owing to the peculiar alignment of the Panama Railroad after leaving Corozal, my plan is to build about 8,500 feet of first-class double-track road from near Corozal straight down to where the canal diverges from the channel opposite the steel pier, and if we did not do that we have got to double track the road anyway and possibly put in a third track. So I think that the question of trackage is independent of any proposition of that sort.

Mr. RANDOLPH. Have you an opinion as to the safety of an earth dam to be constructed, say at Gatun, the height of which shall be 135 feet above sea level, the width on top 100 feet, the upstream slope to be 1 vertical on 2 horizontal, and the downstream slope to be 1 on 2 down to elevation 80 and then to 1 to 4 in 100, or say a bottom width of 2,480 feet at sea level, the head of water against this dam being in extreme cases 90 feet above sea level?

Mr. STEVENS. No; I have no opinion. I will say this, that I think the safety of any dam you build across the Chagres River is dependent on the spillway. I would make the capacity of the spillway four times that of the greatest flood known.

Mr. RANDOLPH. That is, to build a safe dam you have got to make it four times as strong?

Mr. STEVENS. I am talking about the spillway. The whole safety of the dam is dependent on the spillway. If the spillway is too small the dam will go. I believe a dam could be built practically anywhere along the Chagres River that would hold water.

Mr. RANDOLPH. An earth dam?

Mr. STEVENS. Yes, practically.

Mr. RANDOLPH. Earth dam with masonry core?

Mr. STEVENS. I should feel safer with the masonry core.

Mr. RANDOLPH. In your judgment would it be more economical to bring material for the Gatun dam (if it should be decided to build upon that site) from the cutting south of Matachin than to borrow material from other places for that purpose?

Mr. STEVENS. I would not care to venture an opinion. Dredged material makes very compact work.

Mr. RANDOLPH. Have you an opinion as to the relative merits of a sea-level canal of 150 feet bottom width on tangents and a depth of 40 feet, and of a lock and lake canal, the elevation of water in the main lake to be 85 feet above sea level, a channel width of 500 feet except through the Culebra proper, and a depth of 40 feet, and an approach channel from Limon Bay 400 feet wide, the drop from the level of the upper lake to the lower (Panama) lake to be at Pedro Miguel, the lower lake to have a level of 50 feet above mean tide at La Boca, the drop from this lake to sea level to be made near the present low-tide shore line, the total lake navigation—both lakes included—would be about 30 miles, granting that the width through the Culebra cut would be only 150 feet?

Mr. STEVENS. No, sir; I have not. I think either of them would carry a ship through all right.

Mr. RANDOLPH. Basing your estimate upon such knowledge as you now have of the country to be traversed and upon your past experience as a railroad builder through somewhat similar topography, what cost per mile would you assume for a double-track railroad from Mindi to the vicinity of Bohio; joining up to the proposed diversion of the Panama Railroad shown on the maps of the Commission?

Mr. STEVENS. I have looked over that country a little, as I had time; it is very rough and there are two or three elements in there that will have to be decided by the Commission before I could say. I do not see after this canal is built that the railroad is going to be a very big factor in hauling heavy tonnage, which means that you could build a good deal cheaper railroad than you would if you were building a road for handling heavy traffic. I should say that the proper road would cost $75,000 to $100,000 a mile in gold.

Mr. RANDOLPH. After your studies of the conditions in the Culebra cut, have you reached any conclusions as to the proper treatment of the masses of unstable material which tend to slide into the cut from the higher levels?

Mr. STEVENS. There are distinctions to be made there, whether you mean the large masses.

Mr. RANDOLPH. I mean the large masses.

Mr. STEVENS. There are two ways to handle it. You can take it out or drain it. I think it could be drained by a system of tunnels very much cheaper than it could be taken out.

The CHAIRMAN. Did you not do considerable draining on the Great Northern?

Mr. STEVENS. I did. My belief is that that immense mass of material need not be taken out. There are a great many things about sliding material that our profession does not teach us—we have to get the hard knocks.

The CHAIRMAN. How would you handle the slide at Culebra.

Mr. STEVENS. I am firmly of the opinion that the proper method of handling that big slide is by tunneling to get the water out.

Mr. RANDOLPH. You would cut into hard material below it and drain it through?

Mr. STEVENS. I do not know that; I have not made explorations enough yet to know. I base my faith on what I have done in smaller cases. Of course we will have to take some of that material out. I do not want it down in the canal, as we have enough trouble down there, but we have got to get it out on top with high-grade tracks and take it out in the dry season. I do not think it will be necessary to dig it all out. Anyhow I think we need not worry about whether the Panama Canal can be built owing to that slide.

The CHAIRMAN. Do you remember putting in a tunnel revetted with poles?

Mr. STEVENS. I have done such work. Mr. Parsons knows more about that work than I do, he is a tunnel expert.

Mr. RANDOLPH. Have you any ideas differing from projects which have been laid before you which you desire to suggest for incorporation in the final project for this canal?

Mr. STEVENS. I have not, Mr. Randolph; I guess I am the only man in the United States who has not.

Mr. STEARNS. I would like to inquire about the slide. Do you know what was done by the French?

Mr. STEVENS. We have a man in our employ that was here at the time. I have gone up there and found some drains, but I presume some of you gentlemen know more about that than I do.

Mr. STEARNS. I noticed the lines of the drains on the plans, and I wondered if they were from the surface down, or some underground tunnels.

Mr. STEVENS. I do not think there were any drains under the surface.

Mr. STEARNS. Did they prove insufficient?

Mr. STEVENS. Yes. The way the tunnel has got to be driven is to push in a one-man tunnel, say 5 feet by 6 feet, or 5 feet by 7 feet.

Mr. STEARNS. Has it got to be built on clay?

Mr. STEVENS. It depends. If the rock is pockety and filled with clay and the clay is impervious, you might follow on the clay. Generally speaking, the water comes on the surface, then it starts along the line of least resistance, and if the materials are all clay and rock, by a proper system of tunnels, I think, as far as this particular place is concerned, that you could take the water away.

Mr. STEARNS. How is it at points beyond, where a slide has already started?

Mr. STEVENS. I think I would test them very carefully, and if it showed the ground full of little percolating streams that were flowing on the surface, I should certainly treat it.

Mr. HUNTER. Is there anything you would like to say, Mr. Stevens?

Mr. STEVENS. Yes; there is one thing. Give us the type of canal just as soon as you can. You must understand, of course, that I can not, and I do not believe any human being can, do much more than mark time until that is done. I can fix my quarters, and as far as my limited intelligence permits me I can contract for certain rolling stock. I have contracted for two or three million dollars' worth of plant the last month, but beyond that I can not go. Here is this little railroad; we have got to have better terminals at the south end. I want a better yard at La Boca, but you may select an alignment which will interfere with any improvement I might start now.

Mr. HUNTER. That is the one point you are anxious about, Mr. Stevens?

Mr. STEVENS. Yes; but I realize the importance of taking time to settle it right as much as anyone. I think that this proposition is one that grows on a man the more he gets acquainted with it.

Mr. PARSONS. During last winter the chief engineer kept account of certain costs of the work, and during the French régime, before the United States took hold of the work, Major Black, who had been in the Government employ, kept account of the French cost. I would like to ask the engineer if he has analyzed those figures?

Mr. STEVENS. I have not. Mr. Dose brought down all those daily reports.

Mr. GUÉRARD. If I understand correctly, there are no quarries around here, and if we have to make breakwaters or any large rock masonry work I would like to know at what location the quarries could be opened for works of masonry and breakwaters at Limon Bay and Panama also, and where you will find the necessary quantity of sand for this work?

Mr. STEVENS. As far as rock is concerned, I do not think the rock found on the Isthmus could be quarried and cut into dimension stone.

Mr. GUÉRARD. And for the sand?

Mr. STEVENS. The only sand I know of is beach sand, which has to be chosen very carefully, or sand from the Chagres River. I think we could get the sand all right, though.

Mr. GUÉRARD. We must bear in mind that all sand is not good for sea work; that the sea will destroy masonry work with certain kinds of sand.

Mr. STEVENS. Sand which I would call ideal sand would be pure silica.

Mr. GUÉRARD. My question was not answered.

Mr. STEVENS. I could not tell without more examinations. The only sand I know of is sand in the Chagres River, outside of the beach sand. That would have to be decided by investigation.

Mr. GUÉRARD. I have read in the French reports that when they required any small quantity of sand they have had to pay as much as $4 a cubic meter for it, and if a large quantity was required the price would be much more.

Mr. STEVENS. Well that would depend upon the quality of the sand in the Chagres River. That could be obtained at a very much less cost if it is suitable. As far as the quantity is concerned, in most of these streams where there are quick sharp rises, gravel and sand are brought from the upper regions of the river and deposited in a bar, and if that bar is removed, after the next high water it is formed again, so your supply is perpetually renewed.

Mr. QUELLENNEC. I think it is possible to have selected stone to make an artificial sand that is very good.

Mr. RANDOLPH. Have you had any experience in crushing this rock for sand?

Mr. STEVENS. I have had a good deal of experience in crushing trap rock for concrete. Are you familiar with the sandstone quarries of Minnesota? That is a most remarkable deposit of sandstone. The better class of it will average 98 per cent pure silica. I screened that very carefully and sifted it for concrete and heavy foundations, and I think it made the most perfect matrix I ever saw.

Mr. RANDOLPH. Mr. Noble told me he expected to use the trap rock out of his excavations in the same way.

Mr. BURR. I would like to say in regard to that matter of using artificial sand that I believe there are few good rocks that are not perfectly available for that purpose. I have had a pretty extensive experience during the last few years in connection with foundation works in Harlem and the large reservoir which is just now built in New York City. We used and have constantly been using the entire product of the crusher. That was contested very bitterly by certain political critics on part of the city work, but it was established beyond all question to be most excellent material, and I believe that any good rock can be used in precisely the same way; that is, every particle from the crusher can be used.

Mr. STEVENS. I have read and have been told that some experiments have shown that a little admixture of clay in the matrix is a good thing.

Mr. BURR. I only know the results of some experiments. I should not advocate the mixing of clay with sand, but it is a fact that there are a large number of tests at the present time that show that an admixture of a small quantity, I do not know what the limit is, appears to be to some extent advantageous.

Mr. STEVENS. I have been in the habit of washing my rock very clean.

Mr. BURR. I do not think there is any need of it.

Mr. PARSONS. The Chinese have always put clay in their concrete, and judging from the flat arches of their bridges they ought to know something about it.

The CHAIRMAN. If there are no more questions, the Board will excuse Mr. Stevens, thanking him very much for his assistance.

STATEMENT OF MR. F. B. MALTBY.

The CHAIRMAN. This is Mr. Maltby, whom you have all met. He is the division engineer at Colon, has charge of the works here, and also those of the Pacific terminus of the canal at the present time. Will you tell us, Mr. Maltby, how long you have been here?

Mr. MALTBY. A little over six months. I came here on the 23d of March.

The CHAIRMAN. You have had considerable previous experience with dredging and excavations that depend upon a dredge?

Mr. MALTBY. I had charge of all the hydraulic dredging on the Mississippi River below Cairo for about five years.

The CHAIRMAN. What dredging work in the aggregate, yards for example, has been done here by the United States since you took charge—round figures?

Mr. MALTBY. We have handled here in this harbor probably 250,000 yards.

The CHAIRMAN. What type of dredge?

Mr. MALTBY. The French ladder dredge.

The CHAIRMAN. You have not dredged in the other harbor?

Mr. MALTBY. Yes; we are operating another at La Boca.

The CHAIRMAN. How much in the La Boca harbor?

Mr. MALTBY. We have taken out about 350,000 yards since the 1st of June at La Boca.

The CHAIRMAN. Making the total of the two parts 600,000 yards?

Mr. MALTBY. About 600,000 yards.

The CHAIRMAN. Do you have, by hearsay or otherwise, any knowledge respecting the dredging done by the Panama Railroad in the channel leading to the Pacific?

Mr. MALTBY. Yes; I have some information.

The CHAIRMAN. How much work do they do there monthly or annually?

Mr. MALTBY. With a single crew, as the dredge was operated up to about a month ago, we were taking out between 50,000 and 60,000 yards a month.

The CHAIRMAN. That is for maintaining what depth of water at low water?

Mr. MALTBY. We have not an available depth at low water of over 16 feet now.

The CHAIRMAN. Only about 16 feet?

Mr. MALTBY. That is, it is filled up to that extent. We dredged it out deeper than that; they have been dredging there since 1898. The Panama Railroad rented the dredge first from the old French company and then from the United States, and they have maintained a depth in the entrance of about 16 feet.

The CHAIRMAN. Where is the least depth?

Mr. MALTBY. The least depth is over the crest of the bar at the extreme end of the channel, near the island. They took out, as near as I could make out from what records I could find, during the time since 1898, something like 2,500,000 yards.

The CHAIRMAN. That is exclusively in the maintenance of the channel?

Mr. MALTBY. Not exclusively. We have widened the channel. The channel was only 95 feet wide and we have it now 300 feet. We have no more depth but have made it wider.

The CHAIRMAN. Taking the channel as it stands, how much dredging would be necessary to maintain the depth there? How much drift of sand comes in that would affect the channel depth?

Mr. MALTBY. To reduce that to figures would be a rather hazardous guess, but possibly if I state what has filled in in front of the La Boca pier it may give you an idea. In December last, the basin in front of the La Boca pier, that is the iron pier, was dredged out to a depth of 27 feet; a survey on December 24 showed an average depth of about 27 feet with a least depth of 26 feet. On the 31st of May I made a survey over the same area. It showed an average depth of 20 feet and a fraction. I will give you the figures from memory. On the last day of June I made another survey, which showed a fraction over 18 feet; on the last day of July, over the same area, an average depth of between 16 feet and 17 feet. It showed an average filling of about a foot a month, not only for the entire time, but for the last three months where we had monthly surveys, and in September last we dredged it out to 27 feet; that is, 27 feet below spring low tide.

The CHAIRMAN. How much of a tendency to shoal is there at other places?

Mr. MALTBY. The tendency is not great; my data are rather meager as to just how much filling has been done. I am sure of that in front of the La Boca pier. I have not been able to get together so far the maps and surveys that will show just how much.

The CHAIRMAN. I have seen dredges at work there.

Mr. MALTBY. They have worked there since 1898.

The CHAIRMAN. Widening rather than deepening?

Mr. MALTBY. They are widening at the same time; they are deepening to as great a depth as they can; we can only dredge about 38 feet below the water surface. We are dredging it now about 22 feet below spring low tide.

The CHAIRMAN. Twenty-two feet below extreme low water?

Mr. MALTBY. Yes, sir; below spring low tide. We are referring only to spring low tide, because that gives the available depth. If I am not mistaken the last dredging done over the extreme outer end of the channel was in 1903; my impression is no dredging has been done since 1903 and there is 16 feet. The last survey shows 16 feet.

The CHAIRMAN. Do you know as a matter of fact anything of the existence of rock in that channel at any depth above 50? Have you any knowledge respecting the existence of rock besides that at La Boca pier?

Mr. MALTBY. Only except for a couple of hundred feet a little beyond.

The CHAIRMAN. We have been told of an extreme high tide two or three weeks ago of 26 feet. The fluviograph showed that?

Mr. MALTBY. No, sir; our record only shows 23 feet extreme spring tide in the latter part of September.

The CHAIRMAN. How much of an increase over and above the ordinary extreme high tide was that tide?

Mr. MALTBY. I do not understand that it was any greater.

The CHAIRMAN. I am asking you this because of a statement made in Panama yesterday, that the range of the tide reached 26 feet and the wind reached a high velocity.

Mr. MALTBY. I do not think it reached anything like that at La Boca. I have no records here.

The CHAIRMAN. Have you the fluviograph record?

Mr. MALTBY. I can get it.

The CHAIRMAN. I think it would be well for you to send it up, especially this one of Panama, because that has been mentioned as a tide of excessive movement. I would like to inquire simply because I have the impression the observation was taken at La Boca. If you will, look up the record of the fluviograph and see how long it has been maintained and what the record is.

Mr. MALTBY. All right, sir. (See pp. 305–306.)

Mr. STEARNS. Mr. Maltby, do you know what is the difference in the period of high tide at Colon and Panama? When it is high tide in Panama, how much earlier or later is it high tide in Colon?

Mr. MALTBY. I can not tell you that, Mr. Stearns, without looking it up. I believe the periods of high tide are not at the same moment. High tide at Miraflores is considerably later.

Mr. PARSONS. If it is high tide at noon at La Boca, when will it be high tide at Colon?

Mr. MALTBY. We can determine that. The time is given on the records.

Mr. PARSONS. Will you look that up and let us know?

Mr. MALTBY. All right, sir. (See pp. 305–306.)

Mr. HUNTER. Is the silt to which you refer, the necessity for dredging which you say averages about a foot a month—is that due entirely to drift?

Mr. MALTBY. In my opinion, yes. I think very little comes out of the Rio Grande River. It is all due to the effect of the tide.

The CHAIRMAN. You do not think that the accumulation at the La Boca pier comes down the Rio Grande?

Mr. MALTBY. No.

Mr. HUNTER. In what direction is the drift?

Mr. MALTBY. We do not know.

Mr. HUNTER. Which way does it come, east or west?

Mr. MALTBY. The tide is usually up the coast from the east on the Panama side. I have not been able to find any records made by the French or anyone else as to the direction or velocity of these currents. We are trying to get some now.

Mr. HUNTER. Do you find any marked increase in the amount of deposit during the period of high winds?

Mr. MALTBY. No, sir; I do not think so.

Mr. HUNTER. Have you observed that at all?

Mr. MALTBY. My experience is over a rather limited time. We have had no extremely high winds here. I base that opinion largely on the fact that the average monthly filling since last December is practically the same as where we observe by the month.

Mr. HUNTER. What class of material is it, sand or partly silt and gravel?

Mr. MALTBY. I have not seen any gravel.

The CHAIRMAN. At the time of the high water in February of last year at Colon, what height did the water attain as recorded?

Mr. MALTBY. The highest it reached was 1.8 feet above mean low tide. I sent a letter to Major Harrod showing the height the tide reached for four or five days before and after the "norther." It started, I think, two days before the norther. High tide was 0.6 above mean low tide. On the 27th, the second day of the norther, it reached 1.8 feet, and that was the highest. It went down four or five days afterwards to 0.9, I believe, above mean low tide, but the extreme during that time was 1.8 feet above mean low tide.

The CHAIRMAN. Did you take any observations regarding the wave height?

Mr. MALTBY. No, sir; I took that record from the sheet that came off the self-registering gauge.

The CHAIRMAN. These two dredges that have been used are part of the French plant?

Mr. MALTBY. Yes, sir.

The CHAIRMAN. Do you know what their normal capacity is?

Mr. MALTBY. We got about 3,000 yards out of them in about twelve hours.

The CHAIRMAN. Up to what depth?

Mr. MALTBY. The one on this side will only dig to 29 feet; that is, her ladder is short. We removed at La Boca last month 139,000 yards with a double crew; that represents her maximum capacity, because everything moved very smoothly last month.

The CHAIRMAN. For extensive work in this harbor and on the line of the canal, would that type of dredge be the best?

Mr. MALTBY. Not in my opinion.

The CHAIRMAN. Would not be economical?

Mr. MALTBY. No, sir.

The CHAIRMAN. What type of dredge for sea-level canal sections would you recommend?

Mr. MALTBY. From here to Bohio I think we should handle most of the material by hydraulic dredges.

The CHAIRMAN. Up the Rio Grande the same?

Mr. MALTBY. Yes; as far as Miraflores, and some places up through the bottom above there.

The CHAIRMAN. These dredges would reach an output of how much?

Mr. MALTBY. We can build a dredge with a capacity of 1,000 yards an hour.

The CHAIRMAN. And with a dredge that has a capacity of 1,000 yards an hour, and perhaps several of them, you could approximate something of the cost of that work per yard, per unit, from your experience here, allowing for delays and trouble, high water, climate, etc.?

Mr. MALTBY. It certainly should be pumped ashore, including the cost of the plant, for less than 10 cents. The work we are doing is costing us about 7 cents a yard for operation; we can do it for much less with a modern dredge.

The CHAIRMAN. At La Boca?

Mr. MALTBY. At La Boca it is costing about 8 cents; on this side about 7 cents. We are towing farther at La Boca than here. I should say—including the cost of the plant—it should be handled for less than 10 cents. Not to exceed 10 cents.

The CHAIRMAN. That would not include the coral?

Mr. MALTBY. No. There are only 200,000 or 300,000 yards of coral rock.

The CHAIRMAN. Do you think that type of dredge would work all the way up to Bohio?

Mr. MALTBY. I think so.

The CHAIRMAN. Lifting the material over how high a bank?

Mr. MALTBY. As high as necessary; say 10 or 12 feet; more if you need; put it up 20 feet if you want it; simply put a little more coal behind the pump, that is all.

Mr. STEARNS. May I ask a question? He said pump it ashore for less than 10 cents. I presume 10 cents is a safe figure?

Mr. MALTBY. Yes; in my opinion it would not exceed that. I imagine we could put it ashore for 6 or 7 cents. I should say 10 cents would be an outside figure.

Mr. STEARNS. That would not include any administration expense, or anything of that kind?

Mr. MALTBY. It would include every expense properly chargeable against handling that material, including the cost of the plant and the proportionate part of the administration. In other words, just what a contractor would pay for. I do not believe it would exceed 10 cents.

Mr. STEARNS. If that were pumped and put into scows to be conveyed to some other point, how much would it cost?

Mr. MALTBY. We would not pump it into scows. With a hydraulic dredge it would hardly pay to put it into scows. We could do it with a seagoing dredge; pump it into hoppers—a self-contained dredge—a dredge that we probably would have to use in the channel entrances in the open sea, but that would not be an economical way to handle it; we want the material ashore, we do not want it at sea.

The CHAIRMAN. You could not pump it 3 or 4 miles?

Mr. MALTBY. No. The mere cost of pumping it can be done for 2 or 3 cents a yard.

Mr. HUNTER. If you are going to pump this silt, not sand, into scows and carry it 3 or 4 miles, would not the difficulty be you would be carrying 95 per cent water and 5 per cent silt?

Mr. MALTBY. Not that much, Mr. Hunter; you would have a large proportion, but hardly that much.

The CHAIRMAN. I think this material is heavier than what we call silt.

Mr. STEARNS. Why would not 90 per cent of it settle if you discharged it from a 24-inch pipe into a large receptacle? The water would have small velocity from that receptacle to the point of discharge; some would be wasted by the overflow.

Mr. MALTBY. You can see a fair example in the small dredge we are using. Sometimes half the buckets will be full of water, and we fill the barges until the water flows over the sides. I have caught some in a glass and let it settle. In the water that went over the side, 75 per cent is solid material by actual measurement.

Mr. HUNTER. Is not there a great difference in the character of the material lifted by a hydraulic dredge and the character of the material lifted in these buckets? Does not the former stir it all up and blend it all into a very fine solution? Pump it over a bank and give it time to settle, it is a perfect arrangement; pumped into scows it takes hours for it to settle; your scow

will be just filled with dirty water. What class of material is it you expect to get here, Mr. Maltby?

Mr. MALTBY. The material is nearly all clay. The material we are handling now is that material that has been deposited in a channel which has once been excavated. Are you speaking of Colon or Panama?

Mr. HUNTER. Of Panama.

Mr. MALTBY. The material on the Panama side varies very little. In places it is clay, not much sand in it; more sand on the La Boca side than on this side.

Mr. HUNTER. Do you contemplate using cutters on your hydraulic dredge?

Mr. MALTBY. Yes, sir.

Mr. HUNTER. Are you acquainted with any place where that has been done successfully in scows?

Mr. MALTBY. I suppose the best example of that would be all along the Atlantic coast. For handling into scows or into hoppers on board the dredge itself—self-contained dredges—New York Harbor is a splendid example of it, where they handled with two dredges 300,000 yards last month. It is a different material in New York Harbor than here; it has more sand.

Mr. QUELLENNEC. Certainly, these old bucket dredges are not convenient; they are over twenty years old, and now we construct for the Suez Canal dredges of a different type. The solution of the question of economy of a dredging plant is to have the dredges as large as is possible under the circumstances, and I agree with the opinion of your engineer that at Colon and La Boca suction dredges with cutters should be used if possible. All kinds of cutters are not good; there are not many good ones. I know one or two suction dredges with cutters capable of dredging the clay of Mindi. I can say that the cost of material dredged at Suez by suction dredges and disposed through pipes costs less than 10 cents all together, and considering the large quantity to be removed in the sea-level parts of the Panama Canal I think the cost will approximate 10 cents. If it is possible to avoid the scows it is better to put the material into the pipes directly. It is more economical, and with the great width of the canal there should be no trouble from the passing of vessels during construction.

Mr. PARSONS. You said you could dredge as far as Bohio from this side, I think?

Mr. MALTBY. Roughly speaking.

Mr. PARSONS. You spoke of the cost of 10 cents a yard for material put ashore; what portion of the material between here and Bohio would be of that nature?

Mr. MALTBY. Fully nine-tenths of it. We have bored all the way to Bohio, and we find sand and mud. We get out of this indurated clay down here a little above Mindi. Later we bored at Gatun for a channel 45 feet deep, and we did not strike any of it there. There is nothing but sand and silt all the way until we strike the Bohio rock.

Mr. PARSONS. Are you willing to hazard an estimate on the work of excavation—what it should be done for as far as Bohio; the cost per cubic yard?

Mr. MALTBY. I am willing to let my opinion stand as for that class of material. I believe we can build a suction dredge with a cutter that will cut the indurated clay and put it ashore.

Mr. PARSONS. At what cost would you think it would be safe, assuming for the cost of removing the indurated clay?

Mr. MALTBY. Fifty cents a yard.

Mr. HUNTER. Do you think it would be as much as that?

Mr. MALTBY. I want to make my price big enough. We may have to shoot part of it; to shake it up and then cut it.

Mr. HUNTER. To pump it over the dikes on each side, there would be no trouble?

Mr. MALTBY. If we get it into the cutters we can handle it.

The CHAIRMAN. The trouble is to get it into the cutter?

Mr. MALTBY. We may have to shoot it. I believe we can build a cutter that will move the stuff.

The CHAIRMAN. How about the coral rock?

Mr. MALTBY. There are only 200,000 or 300,000 yards of the coral rock; it ought to be taken out for $1 a yard.

The CHAIRMAN. Above Bohio, how do the conditions change?

Mr. MALTBY. My division ends at Bohio; I am not very well acquainted with the conditions above Bohio. I take it from what little I do know of the character of the valley there that it is almost entirely different. We get much more rock. At Tabernilla, for instance, we know there is also an extensive bed of gravel. My opinion of conditions above Bohio is valueless.

Mr. HUNTER. I understand, Mr. Chairman, Mr. Maltby figures approximately, leaving out this coral question, which is only a small one. Between Cristobal and Bohio, 90 per cent of the material would be moved for about 10 cents, probably 10 per cent at about 50 cents; is that what you figure?

Mr. MALTBY. Approximately so. I am answering you offhand. I have not had any preparation for these questions.

Mr. HUNTER. Ninety per cent?

Mr. MALTBY. I believe so.

The CHAIRMAN. Coming up from La Boca to Miraflores?

Mr. MALTBY. As far as Miraflores, I think we found nothing as far as we have bored; we did not get rock, nothing but that alluvial soil.

Mr. PARSONS. What could that be dredged for?

Mr. MALTBY. For the same thing; pump it over high enough to hold it from coming back.

The CHAIRMAN. If that was done by dredging in the Rio Grande Valley and levees were formed on the sides of the canal, that would put the canal between two embankments running to the sea and the drainage of the Rio Grande valley would take care of itself.

Mr. MALTBY. We should make a channel to lead it down.

Mr. CHAIRMAN. The canal would be within the banks?

Mr. MALTBY. Yes, sir; between two banks.

The CHAIRMAN. Would not the cost be higher there on account of the change in tides; you would have to pump that much water?

Mr. MALTBY. I think those figures are safe.

The CHAIRMAN. If you lost it one way you get it at the other.

Mr. MALTBY. I do not believe it would make very much difference; takes a little more coal behind the pump.

Mr. RANDOLPH. What is the greatest height to which you have lifted similar materials?

Mr. MALTBY. The actual lift, I think, has been a very low lift. The combined actual lift and head due to friction in a long line of pipe amount to the same thing. On the Mississippi River it sometimes runs up to 55 feet and 60 feet as shown on the gauge. The actual lift above the surface of the water was 5 or 6 feet.

The CHAIRMAN. In that lift of 6 feet, how long a line of pipe did you have?

Mr. MALTBY. A thousand feet.

The CHAIRMAN. Two feet in diameter?

Mr. MALTBY. Thirty-two inches. That required a very high velocity; much higher than the economical velocity.

Mr. HUNTER. You stated the earth could be removed for substantially the same price on the Pacific. How about the rock?

Mr. MALTBY. That is an entirely different class of rock. It is a hard rock. It would probably cost $3 a yard. It will have to be drilled, blasted, and taken out with a dipper dredge. I suppose it ought not to cost over $3 a yard. There is not much of it.

Mr. STEARNS. Is there not considerable on the line of the canal?

Mr. MALTBY. No.

The CHAIRMAN. The Isthmian Canal Commission estimated it at 485,000 yards, I think. We have French plans which show where the rock is at kilometer 67.5, and above that at 65, 64, and 63. There is quite a lot of rock up there.

Mr. MALTBY. Then up to kilometer 62.

The CHAIRMAN. Sixty-two comes at Miraflores?

Mr. MALTBY. Not as far up as that. You know where we are making the borings, we crossed the canal right at the mouth of the canal; half a mile up the canal we have a boring between 130 feet and 140 feet. We have not explored the canal on the La Boca end as thoroughly as we have on this end.

The CHAIRMAN. I think some of the gentlemen of the Board have expressed the hope that the borings would be carried across the Rio Grande at that lower point.

Mr. MALTBY. About to the mouth of the Rio Grande River?

The CHAIRMAN. About opposite Sosa Hill to below the mouth of the Farfan River.

Mr. MALTBY. The San Juan River?

The CHAIRMAN. It is below the San Juan. A little stream called the Farfan. It will probably show less rock; it will show a shorter distance to rock?

Mr. MALTBY. A shorter distance to rock.

The CHAIRMAN. Suppose breakwaters were built here on the Pacific side, were carried from Guinea Point to Naos Island, material for the breakwater would have to be quarried for the purpose, would it?

Mr. MALTBY. Culebra seems to be an ever-present source of supply.

The CHAIRMAN. The breakwater here, suppose one were made between these two light-houses at Colon, where would the material come from?

Mr. MALTBY. From Culebra.

The CHAIRMAN. Do you know whether there is any rock suitable for a breakwater at Kinneys Bluff; have you ever been there?

Mr. MALTBY. Yes, sir; and I examined it. There is not enough of it showing. The best kind of rock we have would be at Bohio. There is a quarry there with a good face.

The CHAIRMAN. If locks were built at Gatun and that rock was the same, that rock could be used at the breakwater?

Mr. MALTBY. Yes; but that rock is not the same as the Bohio rock. It is indurated clay. So far we have not found any hard rock in the vicinity of Gatun.

Mr. STEARNS. Mr. Chairman, Mr. Maltby speaks of the absence of hard rock at Gatun. I would like to inquire whether he has made sufficient examination of it to enable him to have any opinion as to its suitability for foundation purposes; whether it is solid enough for lock foundations?

Mr. MALTBY. Apparently it is. We have a good example of it here at Cristobal. It is apparently the same material. The dry dock is excavated in that material. Apparently it would make a very good foundation. Furthermore, a part of Cristobal point is built of that same stuff. You can find it on the beach. The corners are rounded off, but the stuff is hard.

The CHAIRMAN. Is this indurated clay, sandy clay where the dry dock is located, the so-called Gatun rock?

Mr. MALTBY. I can not see any difference; a little difference in color.

The CHAIRMAN. Is the basin at that dry dock formed of this clay?

Mr. MALTBY. The entire chamber of the dock is excavated in this rock and there are no other walls.

The CHAIRMAN. I think that material in which the dock was excavated is the same as that on the profiles you showed us for the Mindi River. That was indurated clay. I think that was a different material from what we call rock at Gatun.

Mr. MALTBY. No, sir; that is not true.

The CHAIRMAN. It is the same thing?

Mr. MALTBY. It is exactly the same thing as far as I can see. I can not see a particle of difference between the rock in the east diversion back of Monkey Hill or the rock in which the dry dock is excavated or rock in the holes which we have bored this year or in the sample of rock we have taken out of a core 180 feet below the surface at Gatun. I can not see any difference between it and a piece you can pick out at the dry dock.

The CHAIRMAN. I had the contrary impression, but your observations are much better than mine.

Mr. MALTBY. I have samples in my office from all these places and I can not see any difference. A little difference in color. Those at Gatun are lighter colored.

The CHAIRMAN. Does it change its condition at all when exposed to the air?

Mr. MALTBY. I can not see that it does at all. After it dries it gets lighter in color. I really can not see any difference. Take a piece on the beach and take a piece that has been in the sea water, or take a piece out of the cut or out of a hole 100 feet or more deep, or from the east diversion, it is exactly the same stuff.

The CHAIRMAN. That is the material in the Gatun diversion which stands with vertical walls opposite Monkey Hill 40 feet high, some of it?

Mr. MALTBY. Possibly that high.

The CHAIRMAN. Do you think it is the same material?

Mr. MALTBY. It is the same. I can not see a bit of difference.

The CHAIRMAN. I thought it was harder and drier.

Mr. MALTBY. You can take an ax and cut a chunk out of it.

The CHAIRMAN. It is what the French call in their geological works "argilolithe."

Mr. MALTBY. Indurated clay we call it, for lack of a better name.

The CHAIRMAN. What can you say of the sand of these beaches for making concrete blocks?

Mr. MALTBY. Very little sand on the beach.

The CHAIRMAN. Do you know anything of the history of the blocks they used at Cristobal?

Mr. MALTBY. No, sir; I have no knowledge. All the sand we are using now for what work is going on comes from the interior; river sand. No sand on the beaches here. In some places they get some bank sand.

The CHAIRMAN. From what you know of the material in the harbor as shown by the soundings, would you expect a breakwater of rock to sink deeply into that material?

Mr. MALTBY. I should expect it would; yes, sir.

Mr. HUNTER. Would that apply to this side? Would that apply to a pier constructed on this side?

Mr. MALTBY. Until we got over the coral reef. The coral lies out a few hundred feet; that would not settle; it only runs out a few hundred feet, then we get into mud.

Mr. HUNTER. There is a hard bottom for quite a considerable distance?

Mr. MALTBY. As I remember, it goes out only a few hundred feet.

The CHAIRMAN. You would expect a breakwater made there to sink deeply into the silt?

Mr. MALTBY. I should.

The CHAIRMAN. Suppose a channel were dredged from this harbor 1,000 feet wide, narrowing to 500 feet at Mindi, what protection would that need from wave action?

Mr. MALTBY. I do not see how you are going to protect it except to dredge it out.

The CHAIRMAN. Would you expect it to be rapidly filled by wave action or by lateral drift?

Mr. MALTBY. We have no evidence. My opinion would be that it would fill rather rapidly. It does not seem possible to cut a channel through a flat beach that will stay there. It will have constant pounding from the sea during the dry season. We know it does close up Boca Mindi almost entirely in the dry season. In my opinion it would require almost constant dredging to keep the channel free, as it does at La Boca.

The CHAIRMAN. How much dredging is done at Port Said, Mr. Quellennec?

Mr. QUELLENNEC. Eight hundred thousand cubic meters a year for the entrance; more than 1,000,000 cubic yards.

The CHAIRMAN. That represents a million francs or more?

Mr. QUELLENNEC. With all the expense of administration and repairing, a million francs.

The CHAIRMAN. Much dredging at Suez?

Mr. QUELLENNEC. No; very little.

The CHAIRMAN. Mr. Welcker, is there much dredging at the North Sea Canal entrance?

Mr. WELCKER. Always.

The CHAIRMAN. How much?

Mr. WELCKER. Very little difference; 400,000 or 500,000 cubic meters annually to keep the entrance open. It would cost not more than 0.60 or 0.70 guilder per cubic meter.

The CHAIRMAN. Sixty one-hundredths of a guilder?

Mr. WELCKER. The unit is a guilder. The guilder is 40 cents. Two francs to a guilder.

Mr. QUELLENNEC. For 800,000 cubic meters it is 700,000 francs at Suez.

The CHAIRMAN. With a sea-level entrance to the Panama Canal at the Pacific side, Mr. Maltby, would you expect we would need constant dredging to maintain it?

Mr. MALTBY. I should not expect to find very much filling after getting well up into the canal. The entrance into the bay, the indications are, will require a good deal of dredging. We have been dredging it for several years. After we get up into the canal I should not expect to find a very great amount of filling.

The CHAIRMAN. I was trying to get at your idea what the sea-level entrance to the canal would probably require at La Boca in the way of dredging.

Mr. MALTBY. Probably, with an entrance 40 feet or 45 feet deep at low tide, it would run up close to 1,000,000 yards a year, in my opinion.

The CHAIRMAN. Do you think there would be any security obtained from a breakwater at Guinea Point to prevent the sweep of the waves?

Mr. MALTBY. It might be some assistance. I do not believe it would be worth what it costs.

Mr. PARSONS. At what rate is the actual cost of dredging to keep the present channel open? How much do they spend a year?

Mr. MALTBY. Fifty thousand dollars a year. It would not cost as much per yard, not nearly as much. Dredging in New York Harbor is being done at less than 5 cents a yard now.

Mr. STEARNS. Would the dredging on the Atlantic side cost more per year in order to maintain the channels than on the Pacific side—a straight channel on the Atlantic side?

Mr. MALTBY. I suppose probably not. I think the channel entrance, in the first place, would be somewhat shorter. There is practically no tide here, which would tend to lessen the amount of filling, lessen the amount of material to be removed every year.

The CHAIRMAN. Do you think that the silt that is dredged every year comes from the sea by the influence of the waves and by reason of the tide?

Mr. MALTBY. It must be brought in by the sea, because these banks are getting higher all the time.

The CHAIRMAN. The silt all comes out of the sea? Does the silt you are dredging at La Boca come directly from the sea into the channel?

Mr. MALTBY. I do not know. The general opinion is that a large portion comes from the Rio Grande. From the character of the mud we handle, from the character of the stream itself, I believe very little of it comes out of the Rio Grande. I do not think the water carries very much sediment. The general trend of the currents is in this direction [indicating].

The CHAIRMAN. There is a map in the canal office at Panama which shows the record of the French observations on currents in Panama Bay, and shows where the tides meet coming from the west or from the east. It shows by arrow marks the direction and velocity of these currents. I have never undertaken to study it very carefully, but I have seen the map and examined it more than once. It is quite a carefully prepared paper.

Mr. WELCKER. I have dredged this year in Holland and transported by seagoing dredges for 6 and 7 kilometers for a quarter of a franc per cubic meter.

Mr. TINCAUZER. Have you seen a norther here?

Mr. MALTBY. I have not seen one.

Mr. STEARNS. As to the cost of rehandling dredged material pumped into a dam?

Mr. MALTBY. I gather from your idea that the material is to be dredged in the canal, taken to the vicinity of the dam, and then pumped into it?

Mr. STEARNS. Yes.

Mr. MALTBY. The rehandling would cost considerably less than the original handling, the material being already loose. We would handle a larger percentage of solid material with the same discharge, requiring no agitating machinery. There would be the cost of a long pipe line and the levees, the cost to be absorbed in a large yardage, and it would not add materially to the unit cost. I should say that it would be safe to say that it would cost us 10 cents to dredge it; it certainly would not cost any more to rehandle it. In other words, to put it into a dam, say 40 or 50 feet high, would cost not to exceed 20 cents per yard.

The CHAIRMAN. Including the wear and tear of the machinery?

Mr. MALTBY. I was going on the assumption that the rehandling machinery would be additional machinery.

The CHAIRMAN. Did you make any silt observations of the Chagres at Bohio?

Mr. MALTBY. No, sir.

Mr. STEARNS. There was one other question: What percentage is sand and what percentage is clay at Gatun? The sample you gave seemed to indicate a large percentage of sand, I think.

Mr. MALTBY. As far as I know, Mr. Stearns, that is a fair average sample we showed you. It was intended to show what we consider a fair average sample of the material.

Mr. STEARNS. Would not a material of that kind settle quite quickly in a scow if it were pumped into it?

Mr. MALTBY. A large proportion of it would. Some might go overboard. I do not think I would recommend the use of a suction dredge to load into scows. If you are going to take it up in scows I would load it with a dipper dredge, because you do not want to mix it up so much. My idea of a hydraulic dredge was to pump it over the bank and let it go. If we were going to put it into scows, the first handling would better be with a dipper dredge.

Mr. STEARNS. What would that cost?

Mr. MALTBY. It would not cost much more. The plant would not have quite as much capacity.

Mr. RIPLEY. For the same amount of money you could get the same capacity with dipper dredges?

Mr. MALTBY. Yes, sir.

Mr. RIPLEY. You put in two dipper dredges where you put in one hydraulic dredge?

Mr. MALTBY. Yes.

At 12.45 recess was taken.

ISTHMIAN CANAL COMMISSION,
DEPARTMENT OF ENGINEERING AND CONSTRUCTION,
OFFICE OF DIVISION ENGINEER,
Cristobal, October 14, 1905.

SIR: Referring to certain questions asked me by the Board of Consulting Engineers recently, I have the honor to inclose herewith a table showing the range between high and low tide at the Panama Railroad pier in La Boca, between September 22 and October 10, 1905.

You will note that the extreme range between high and low tide is given as 19.9 feet on October 1. Also that a note states that this tide was abnormal on account of a strong southeast wind. The wind evidently did not affect it to any great extent, as the range on the day before approached very closely to it.

I find I was mistaken in making the statement regarding the tide record at Naos Island. I find this record has not been maintained continuously. I have no record of it at all. In fact, my records of tidal observations are not very complete at La Boca pier prior to August 1. Since that date we have gotten records at the Panama Railroad pier and at kilometer 65. The information given will, however, answer the question of the Board as to whether there was an abnormal tide during September. Evidently there was not. The previous spring tide, which occurred about September 1, had a range of 19.1 feet.

Referring to Mr. Parsons's question as to the difference in the time of the tide at La Boca and Cristobal, I find, on comparing the records for a week, that high tide at Cristobal averages eight hours and fifty-four minutes later than at La Boca; or, in other words, with high tide at noon at La Boca, high tide at Cristobal would occur at 8.54 p. m.

I hope this will give you the desired information on this subject.

Very respectfully,

F. B. MALTBY,
Division Engineer.

Gen. GEORGE W. DAVIS,
Chairman Board of Consulting Engineers,
Washington, D. C.

Tidal data at Panama Railroad pier, September 22 to October 10, 1905.

Date.	Time (A. M.).			Time (P. M.).			Date.	Time (A. M.).			Time (P. M.).		
	High water.	Low water.	Range.	High water.	Low water.	Range.		High water.	Low water.	Range.	High water.	Low water.	Range.
			Feet.			*Feet.*				*Feet.*			*Feet.*
September 22	8.40	2.30	8.4	8.50	3.15	7.8	October 2	5.35	11.45	19.5	6.00	.....	.....
September 23	9.30	3.20	7.5	10.00	4.05	7.7	October 3	6.25	12.15	17.5	6.45	12.45	16.6
September 24	10.45	4.45	7.9	11.15	5.20	8.8	October 4	7.20	1.10	15.4	7.40	1.35	14.9
September 25	12.00	5.45	9.1	.....	5.20	.....	October 5	8.00	2.00	12.8	8.40	2.30	12.2
September 26	12.30	6.45	10.8	1.00	7.40	12.5	October 6	9.05	3.05	10.1	9.40	3.20	10.3
September 27	2.05	8.00	13.8	2.00	8.25	14.7	October 7	10.10	3.55	8.6	11.05	4.45	9.8
September 28	2.40	8.50	16.5	2.55	9.00	17.4	October 8	11.35	5.15	8.6	11.55	6.05	9.5
September 29	3.20	9.30	19.0	3.30	10.05	18.7	October 9	.....	7.00	.....	12.45	7.00	9.7
September 30	4.00	10.15	19.7	4.30	10.30	19.5	October 10	1.05	7.30	10.9	1.35	7.50	11.9
October 1	5.00	11.05	[a] 19.9	5.15	11.20	18.6							

[a] October 1, tide abnormal on account of strong southeast winds.

STATEMENT OF MR. H. F. DOSE.

Mr. Dose appeared before the Board at 2.15 p. m.

The CHAIRMAN. Mr. Dose, did you bring with you some data concerning the excavation at Culebra?

Mr. DOSE. Yes, sir.

The CHAIRMAN. Will you inform us what you know about the quantities of material removed at Culebra since the Americans took charge, and the cost of doing it?

Mr. DOSE. Since the 1st of July, 1904, they have moved in the neighborhood of 700,000 cubic yards; about 700,000, perhaps 800,000 yards up to date.

The CHAIRMAN. That begins with July 1?

Mr. DOSE. Yes, sir.

The CHAIRMAN. The record for May and June you did not get?

Mr. DOSE. No, sir.

The CHAIRMAN. What do you know about the record of cost for that work?

Mr. DOSE. Itemized records were kept of the cost of the work in detail, but I do not think they included the entire cost, only the pay rolls at Culebra—the salaries of the men who were directly connected with taking out material—division superintendents, firemen, engine drivers, conductors, and steam-shovel men.

The CHAIRMAN. Does it include repairs?

Mr. DOSE. No, sir; not exactly. The repairs and items of that nature come under arbitraries.

The CHAIRMAN. Did it include fuel?

Mr. DOSE. Yes.

The CHAIRMAN. What is the price they are paying now at Culebra for coal?

Mr. DOSE. I do not know, I can look it up; I think $7.

The CHAIRMAN. I remember distinctly there was a price made with the Panama Railroad for coal at Culebra at $5.50.

Mr. DOSE. I am not sure about that.

General ABBOT. Did you give the costs of 800,000 yards?

Mr. DOSE. I have the monthly reports here.

The CHAIRMAN. Are these quantities of cost stated in the schedule by months?

Mr. DOSE. Yes, sir. This is the cost for the entire year, from July 1, 1904, to June 30, 1905.

The CHAIRMAN. Are the costs subdivided and under headings?

Mr. DOSE. Yes, sir.

The CHAIRMAN. Read off the headings.

Mr. DOSE (reads): Plant covered by arbitraries $0.0492 per yard.

The CHAIRMAN. Is that an arbitrary allowance?

Mr. DOSE. That is an arbitrary allowance; yes, sir.

Plant arbitrary	$0.0493
Mining	.0944
Loading	.1042
Transportation to dumps	.1618
Dumps	.0548
Track maintenance	.0702
General expenses	.0518
Total	.5865

Or, say, 59 cents.

The CHAIRMAN. Is that for the year?

Mr. DOSE. For the entire year, General.

The CHAIRMAN. Where does the unloading of cars come into those figures?

Mr. DOSE. In the dumps, $0.548. The loading costs 10 cents.

The CHAIRMAN. And the unloading?

Mr. DOSE. A little over 5 cents.

The CHAIRMAN. That includes bank spreading?

Mr. DOSE. Yes, sir; pushing clear of the track and dump margins.

The CHAIRMAN. That is for the whole year?

Mr. DOSE. Yes, sir; we now use the new bank spreaders. We formerly used a plow made in the Culebra and Cristobal shops.

The CHAIRMAN. The total for all is?

Mr. DOSE. $0.5865. The total amount for the year was 741,644 yards.

The CHAIRMAN. For example, as a resident engineer, was your salary compnted in that?

Mr. DOSE. The superintending was included in that.

The CHAIRMAN. The clerical force?

Mr. DOSE. The clerical force was partly included in it.

The CHAIRMAN. Why part and not all?

Mr. DOSE. The clerical force of the different superintendents was included in that, but the clerical force of the division engineer was not included. There was an arbitrary that carried the general expenses.

The CHAIRMAN. The arbitrary you have given us is for plant, is it not?

Mr. DOSE. I will read you what the arbitrary is.

The CHAIRMAN. An arbitrary for plant?

Mr. DOSE. Yes; the arbitrary for plant.

The CHAIRMAN. So there is no allowance for general expenses in that beyond what you say?

Mr. DOSE. General expenses, $0.0518 per yard.

The CHAIRMAN. That has been included in the 58?

Mr. DOSE. Yes.

The CHAIRMAN. You state something about certain clerical forces not being included and others who were. What was and what was not included?

Mr. DOSE. The clerical force in the resident engineer's office is not included in these charges.

The CHAIRMAN. But his own salary is?

Mr. DOSE. Yes, sir.

The CHAIRMAN. And all the other assistant engineers?

Mr. DOSE. No, sir. The assistant engineers are not included—Ruggles's force is not included, for instance.

Mr. PARSONS. Last winter I discussed that with the chief engineer and he told me he had included in the cost of the work the men that the contractors would have to employ; that engineering forces would have to be employed by the Commission anyway—that is, whether the work was done by contract or not—and therefore he charged that part of the engineering work to the general cost of administration, but he included in this cost the force of superintendents and clerks that a contractor would have.

The CHAIRMAN. There are twelve months here; how do those averages for months compare one with another?

Mr. DOSE. I do not think I can give you them for the entire year, General. I can give them to you from October:

Month.	Output.	Cost.
	Yards.	*Cents.*
October	19,695	54.06
November	28,860	50.12
December	42,935	52.83
January	70,650	47.80
February	75,200	46.53
March	132,840	43.28
April	126,749	52.47
May	75,935	83.81
June	76,905	102.74
July	78,570	103.54
August	49,210	153.85

Mr. HUNTER. What makes the difference, Mr. Dose?

Mr. DOSE. The rainy season and change in rate of pay for labor.

Mr. BURR. What was the effect?

Mr. DOSE. Trains off the track and soft character of the material.

The CHAIRMAN. You have not September figured out yet?

Mr. DOSE. No, sir; I have not the figures.

Mr. PARSONS. May I ask Mr. Dose to give details of the maximum and minimum months?

Mr. DOSE.

August—	
Plant arbitrary	$0.0600
Mining	.2352
Loading	.2506
Transportation	.6147
Dumps	.0993
Maintenance of tracks	.1494
General expenses	.1293
Total	1.5385
March—	
Plant arbitrary	.0600
Mining	.0750
Loading	.0705
Transportation	.1105
Dumps	.0471
Maintenance of tracks	.0435
General expenses	.0262
Total	.4328

Mr. WELCKER. Mr. Chairman, can Mr. Dose tell us how many units were involved?

Mr. DOSE. This only includes what came directly under the charge of the division engineer. It did not include the work done for us by the mechanical department, or the building of houses. It is merely the operating of the trains and shovels at that place.

The CHAIRMAN. Does it include sanitation?

Mr. DOSE. No, sir; it does not even include the entire pay roll.

The CHAIRMAN. What is omitted?

Mr. DOSE. Ruggles's men, the surveyors, were omitted. They were doing topography, estimating the quantities taken out, the number of cars, the line for dumping grounds, and whatever there was to be done of that nature in connection with the work at Culebra.

The CHAIRMAN. What was the idea of omitting it?

Mr. DOSE. It did not enter into the moving of material.

The CHAIRMAN. If they were running lines for dumps I should think it would.

General ERNST. That kind of expense would be incurred anyhow if you were doing it by contract.

Mr. DOSE. In the month of March we had two French excavators at work.

The CHAIRMAN. How many shovels?

Mr. DOSE. Six shovels.

Mr. HUNTER. Were they the new shovels?

Mr. DOSE. Yes, sir; we loaded some material by hand, perhaps 700 cubic yards.

The CHAIRMAN. What were the tools at work in August?

Mr. DOSE. August is not really a good month to take, because the shovels worked only half the month and some were pulled off to do preparatory work, to prepare tracks and dig trenches for drainage purposes and do work that really should not have been charged up to the outpnt of the shovel.

The CHAIRMAN. Is it included in these figures?

Mr. DOSE. Yes, sir.

The CHAIRMAN. Then part of this expense that is converted into unit prices of $1.53 represents work that was not excavation in a direct way?

Mr. DOSE. Yes, sir.

The CHAIRMAN. It was to remedy damages and improve conditions. It was work that a contractor would have to do?

Mr. DOSE. Yes, sir.

Mr. RIPLEY. Mr. Chairman, in the item of transportation, does that include the grading and laying of tracks to the dump grounds?

Mr. DOSE. No; the transportation is merely the hauling of the cars from and to the shovels.

The CHAIRMAN. Not the making of dump tracks?

Mr. DOSE. No; that comes under tracks and dumps.

The CHAIRMAN. Is it here?

Mr. DOSE. Yes, sir; it is.

Mr. STEARNS. Under what item are the tracks?

Mr. DOSE. It comes under the item of dumps.

Mr. STEARNS. Does that include the tracks leading to the dumps?

Mr. DOSE. It includes the tracks right on the dumps; under maintenance of tracks, tracks leading to the dumps are included.

Mr. RIPLEY. Then the item of dumps does not include the cost of leveling material and shifting tracks?

Mr. DOSE. Another item of tracks comes under arbitraries.

The CHAIRMAN. What is that?

Mr. DOSE. That is arbitrary, the 1 cent is allowed for them. It does not include the laying and shifting of tracks or steam shovels on the dumps.

The CHAIRMAN. The track work is in two places?

Mr. DOSE. Part of it is in arbitrary and part of it in maintaining tracks.

Mr. PARSONS. Mr. Dose, Mr. Guérard has requested me to ask you how the yardage is measured, in place or on the cars?

Mr. DOSE. The yardage is computed from the cross sections and that is checked by the car report.

General ABBOT. In place?

Mr. DOSE. Yes, sir. They are from the cross-section notes and were checked by the car reports.

Mr. HUNTER. The reason why the quantity in August fell so low is because the steam shovels were taken off to do other work?

Mr. DOSE. Yes, sir.

Mr. PARSONS. Mr. Dose, have you any idea how the expenses ran during September, the past month?

Mr. DOSE. The report is not out yet, Mr. Parsons, but will be about $1.50, perhaps higher.

The CHAIRMAN. You had better get the report and send it in, because it would make a complete record for a year.

Mr. HUNTER. What was the material composed of?

Mr. DOSE. Most of this material was clay; the percentage of solid rock was very small.

The CHAIRMAN. Was most of it blasted?

Mr. DOSE. No, sir.

Mr. BURR. I would like to ask if this clay was the top soft material?

Mr. DOSE. It was a soft material at one end of the cut and at the other end of the cut it was mostly soft material that did not require blasting.

Mr. PARSONS. Taking into account that it was done in the wet weather, is it more or less expensive than handling rock?

Mr. DOSE. Sometimes we could not handle that material at all; we had to stop work. It would be more expensive than hard rock in the rainy season.

The CHAIRMAN. You could obtain figures for September to supplement these?

Mr. BURR. In that September statement, Mr. Chairman, it seems to me it would be quite essential that Mr. Dose should indicate about how the plant was engaged, whether it was engaged in other matters which did not involve excavation. Can you give us that explanatory note in connection with the September report?

Mr. DOSE. Yes, sir; I think so.

The CHAIRMAN. You can send it up in the next steamer; perhaps you can get it to-morrow before we leave.

Mr. DOSE. Yes, sir. (See Appendix K.)

The CHAIRMAN. Have you made any inquiries since you have been here about whence those figures were obtained for the computed excavation and total yardage in the Culebra? There were noted some discrepancies in a comparison with the records of the Isthmian Canal Commission—the matter of which General Hains was speaking to you.

Mr. DOSE. Yes, sir; I think I found the explanation.

The CHAIRMAN. What is it?

Mr. DOSE. The section of prism used in making the last estimate is different from the prism used in the Isthmian Canal Commission's estimate of 1899–1901. The slopes were 2 on 1 in the last estimate and 1 on 1 in the former.

The CHAIRMAN. Mr. Bertoncini has given Mr. Harden a sheet with quantities, has he not?

Mr. DOSE. Yes, sir. It makes the width at the berm 100 feet wider in that case than it did in the Isthmain Canal Commission's project.

The CHAIRMAN. Why should not that apply to the sea-level figures?

Mr. DOSE. It applies to all.

The CHAIRMAN. There did not seem to be so large a discrepancy.

Mr. DOSE. I do not know about that.

General ABBOT. During the month of August were there any of the old French excavators in use?

Mr. DOSE. No, sir. The last excavator was placed out of commission in June or July.

Mr. HUNTER. What is the largest amount you have taken off with one of these new shovels?

Mr. DOSE. It was over 1,000 yards.

Mr. BURR. There have been many days in which the amount removed averaged from 1,000 to 1,300 or 1,400 yards per shovel.

Mr. RIPLEY. Mr. Chairman, in the item of mining the cost seems to be rather high for clay, and I would like a little further explanation of what the mining actually consisted of.

Mr. DOSE. For the month of July the total output was 78,570 cubic yards, and the material actually handled was 15,935 hard rock, 11,315 soft rock. The hard rock cost 45 cents and the

soft rock 22 cents, and the cost of mining, taking the total cost of mining and the total number of yards removed, will bring the mining 12 cents; but it really cost 45 cents and 22 cents, because a great deal of the material removed did not require mining.

The CHAIRMAN. Have you an opinion, Mr. Dose, as to the proper unit cost for material taken out with a proper plant, proper organization, tracks, dumps, etc.?

Mr. DOSE. It is pretty difficult to say; it depends entirely upon the season. Some years it will cost a good deal more than in others, and it depends upon health conditions and the labor and so many other things that it is difficult to say. It ought to cost as much as or more than at home. For instance, yesterday it rained; if we had been working full blast it would have done much harm. We would have had to shut the work down entirely for perhaps three days. The tracks wash out; there are slides and other unsatisfactory conditions following a heavy shower, and it is pretty hard to guess. Of course, I have my own view of it, but I may be mistaken.

Mr. HUNTER. What are your own views?

Mr. DOSE. I really do not think you can take out the hard rock and the material in the Culebra any cheaper than you can at home. For material like that in the Culebra the cost is about 70 cents in the United States; softer material perhaps you can handle for 50 or 65 cents.

The CHAIRMAN. You say you could not handle it any cheaper. I should think it would cost more.

Mr. DOSE. I do not know whether it would cost much more than it would at home, but it would be pretty difficult for me to say how much it would cost, there are so many considerations entering into it.

Mr. HUNTER. You have been there every day?

Mr. DOSE. No, sir. I was only there a comparatively short time.

General ABBOT. When were the steam shovels introduced? You say the old excavators were dropped out in June; when did the steam shovels come in?

Mr. DOSE. Steam shovel 101 started November 11.

The CHAIRMAN. Of those two types of shovels, which is the more effective, the 5-yard dipper or the 2-yard?

Mr. DOSE. In that soft material on the hillside I prefer the lighter shovel. It weighs a good deal less, it is easier to handle, and for that work I prefer the lighter shovel; for the heavier rockwork a heavier shovel.

The CHAIRMAN. The dry season and the wet season compared, what proportion of the earth has to be shoveled out of the dump cars, and how much will run out?

Mr. DOSE. I was not up there in the dry season.

The CHAIRMAN. What proportion now?

Mr. DOSE. Of the red material we have to shovel out nearly 85 per cent.

Mr. STEARNS. I have been somewhat surprised at the small expense of the dumps given by Mr. Dose. Taking it by the year the loading cost has been twice as much as for dumping, or very nearly, and that seems to be the general rule, whereas I had understood it cost more to dump than to load

Mr. RIPLEY. The transportation is really an item of dumping.

Mr. BURR. I think the dumps referred to in conversation would, as I understand it, include not only the dumps proper, but the whole scheme of getting the material from the excavators to the dumps and disposing of it.

The CHAIRMAN. Will you please look and see whether that item of transportation does not cover the unloading of the cars?

Mr. DOSE. I am sure, General, it does not. The transportation includes the train crews, cost of fuel, etc., taking cars from the shovels to the dumps and back to the shovels again. The cost of dumps includes the men on the dumps, dumping the cars, and throwing the tracks. The discrepancy arises because the shovels were not working half of the time, thereby increasing the cost of loading per yard actually excavated way beyond what it ought to be.

The CHAIRMAN. What are they charging for coal now?

Mr. DOSE. According to these figures here coal costs $7 a ton.

The CHAIRMAN. Seven dollars?

Mr. DOSE. Yes; 35 tons of coal, $245.

Mr. RIPLEY. That is the cost loaded on the tender?

Mr. DOSE. That is the cost of the coal on the tank of the engine.

The CHAIRMAN. I am pretty sure that the price charged by the Panama Railroad for coal at Culebra was $5.50, but this includes the cost of delivering the coal to the engine.

Mr. HUNTER. Have you formed any opinion, Mr. Dose, of how many steam shovels could economically and efficiently work at one time, if you had the whole of the Culebra cut in operation? Have you worked out any scheme at all?

Mr. DOSE. I have not, Mr. Hunter.

Mr. HUNTER. Have you any view of your own, working on the different levels the whole 7 miles of country?

Mr. DOSE. It is not so much the keeping of the shovels at work as of taking the material away from them; I am not prepared to answer that. As to the matter of prices, in the dry season you could do it very cheaply; in the rainy season it may cost a good deal and it is pretty difficult to arrive at a conclusion.

Mr. HUNTER. Do you not hope for greatly improved conditions during the rainy season?

Mr. DOSE. Yes, sir. Of course you have to consider that the lower down you go and the deeper the cut the more it will cost; when you get down to where the water bothers you will have to put in heavy pumps and a good many things will make it more expensive.

Mr. BURR. Will you put in any pumps above sea level? Can not you drain your cut?

Mr. DOSE. We have to contend with a good many small streams, the Obispo, Lirio, etc., and they all have to be taken care of. We would either have to let some of them into the cut or build expensive aqueducts or tunnels to divert them. This applies especially to the Lirio.

Mr. STEARNS. In speaking of the cost of work in the States, do you refer to eight hours of labor or ten hours of labor?

Mr. DOSE. I refer to eight hours.

Mr. PARSONS. When did eight hours go into effect here?

Mr. DOSE. The 1st of June.

Mr. PARSONS. That is one reason for the increase of cost?

Mr. DOSE. Yes; that is one reason. The cost per cubic yard for material excavated in June was $1.0274; the increased cost of handling this material for the month of June over May is due to the change from ten hours to eight hours per day.

Mr. BURR. The hours were shortened and wages increased?

Mr. DOSE. Yes, sir.

Mr. GUÉRARD. What is the salary of a laborer per day?

Mr. DOSE. Seventeen and one-half cents silver an hour for eight hours' work, and time and half time for overtime or work on Sundays.

The CHAIRMAN. Do you think the change in the labor prices made a net increase of 33 per cent?

Mr. DOSE. The reduction in hours and the increase in wages. The gold men also got a slight increase throughout.

The material below Pedro Miguel, when we get out of the rock, and the material below Obispo, can be handled for a very small amount. It is mostly gravel and sand and soft clay.

Mr. PARSONS. Obispo to where?

Mr. DOSE. As far as Bohio, with the exception of the little rock at San Pablo.

Mr. PARSONS. Is not a good deal of that material between Bohio and Obispo dredgable?

Mr. DOSE. I think almost all of it can be handled with a centrifugal pump if you can get one in there.

Mr. BURR. How much rock is there between Bohio and Obispo?

Mr. DOSE. The only part that is rock is in the vicinity of the San Pablo lock site. There is a little more at about kilometer 45, just before Obispo.

Mr. BURR. It is a small percentage of the total?

Mr. DOSE. Yes, sir.

Mr. BURR. Would that be true for the sea-level plan?

Mr. DOSE. Yes, sir.

Mr. BURR. Is the rock hard?

Mr. DOSE. Some rock around San Pablo is very hard.

Mr. BURR. Have you any profile of the line which exhibits the results of the latest borings along the center line of the canal?

Mr. DOSE. I think there is one here.

Mr. BURR. Does that cover the entire line from Bohio to Pedro Miguel?

Mr. DOSE. Yes, sir.

Mr. BURR. Then we have that before us.

The CHAIRMAN. We had the same thing in Washington, but it was not complete; we have it now completed to date, and, Mr. Dose, you are making up the sheet showing sections on each hole for each kilometer through the Culebra cut, with samples?

Mr. DOSE. Yes, sir.

Mr. Dose was excused at 3.20 p. m.

STATEMENT OF MR. CHARLES BERTONCINI.

The CHAIRMAN. Gentlemen, this is Mr. Bertoncini, who has been a draftsman in the employ of the old French company, the New Panama Canal Company, and by the United States since the work was taken over. He is familiar with the records and plans in the canal office at Panama. He has some data you have not seen before, that I have asked him to bring here. Mr. Bertoncini, will you show us the profile of the geological section of the canal we saw yesterday in the canal office? This section is 40 to 50 feet long and it shows the character of the material as developed by borings before the year 1883 for a sea-level canal. The borings were taken at short intervals along the line?

Mr. BERTONCINI. According to the importance of the place. In some places very close together and in some more distant.

The CHAIRMAN. Did they bore to the bottom of the sea-level canal?

Mr. BERTONCINI. Yes, sir; in nearly every case.

The CHAIRMAN. Do you remember the name of the engineer who had this work done?

Mr. BERTONCINI. It was made by not only one but several. There were several parties. All data were centralized in the office.

The CHAIRMAN. Who was at the head of that office?

Mr. BERTONCINI. M. Roux and M. Cannelle were the two principal ones; there were several others.

The CHAIRMAN. You have the original of this in the office?

Mr. BERTONCINI. Yes, sir.

The CHAIRMAN. We can take this with us?

Mr. BERTONCINI. Yes, sir.

The CHAIRMAN. This is a longitudinal section throughout the whole canal line as derived from borings made before 1883?

Mr. BERTONCINI. Yes, sir.

The CHAIRMAN. This was translated and copied during the last year?

Mr. BERTONCINI. Yes, sir.

The CHAIRMAN. The notes in French translated into English and copied this year?

Mr. BERTONCINI. Yes, sir.

The CHAIRMAN. What method was used in boring?

Mr. BERTONCINI. Some were made by diamond drills and some in a different manner. You have seen the cores we have in the office showing samples of the material taken from these borings.

The CHAIRMAN. Did you use a pipe with a jet of water?

Mr. BERTONCINI. In some cases; yes, sir.

The CHAIRMAN. Were there any test pits?

Mr. BERTONCINI. Some pits were made, but very few; they were made in 1886, 1889, and 1892, and later in 1896 also.

The CHAIRMAN. Did any of these pits at Culebra go to the bottom of the proposed canal?

Mr. BERTONCINI. The pits in the low ground did, but not in the central part of the cut.

The CHAIRMAN. Is the route of this profile substantially the same as the route of the present canal?

Mr. BERTONCINI. Yes, sir; we have always used the same axis for the sea-level canal; the one that was traced at this time.

Mr. STEARNS. These later borings are with the diamond drill?

Mr. BERTONCINI. Yes, sir.

The CHAIRMAN. At this time had any borings been made on the site of the Gamboa dam?

Mr. BERTONCINI. Yes, sir.

The CHAIRMAN. Was there a general report that went with this sheet?

Mr. BERTONCINI. Yes, sir; there was a report.

The CHAIRMAN. Is there a copy of it in Panama?

Mr. BERTONCINI. I have seen partial reports and sketches. There are details of each of these borings.

The CHAIRMAN. No general summary of it all?

Mr. BERTONCINI. There was one made, but I could not say where it is. I know it was made and sent to Paris.

Mr. PARSONS. This, of course, shows the surface of the land without any excavation being done?

Mr. BERTONCINI. Yes, sir.

Mr. BURR. That gives the original elevation of the Culebra summit then. What is the elevation of the Culebra summit?

Mr. BERTONCINI. 101.66 meters (333.5 feet).

Mr. PARSONS. These figures are the elevation above sea level?

Mr. BERTONCINI. Yes, sir.

Mr. PARSONS. On the center axis?

Mr. BERTONCINI. Yes, sir.

Mr. PARSONS. Sometimes the slopes went higher or lower at the cross sections?

Mr. BERTONCINI. Yes, sir; altitude 101.66 was in the middle of the axis. On both sides of the cross section it was higher.

The CHAIRMAN. Mr. Bertoncini, that map we were looking at yesterday, will you please unroll it. This is an original. It shows the canal as it existed when work ceased by the old company. The plan has been copied many times, but on this sheet are also general profiles of all the proposed river deviations, the profiles as they existed at the time of the cessation of work and the extent to which excavations had been carried. This relates to all the deviations throughout the whole canal line, and it exists in no other form that I am aware of. I do not think this sheet has ever been printed. Mr. Bertoncini says he is confident a copy of it was sent to Paris.

Mr. BERTONCINI. It is a topographic plan made in Panama.

The CHAIRMAN. Is there no other copy?

Mr. BERTONCINI. There are a very few. This in yellow is hand-made. This was a sort of progress map; every three months we used to show the work done.

Mr. PARSONS. To what year does this map show progress?

Mr. BERTONCINI. It was made in February or March, 1889; the last work done; the last progress map.

The CHAIRMAN. Do not some of the reports of the second company show this information?

Mr. BERTONCINI. No, sir; this is an original work. There are three maps. A map like this was sent to Paris.

The CHAIRMAN. Mr. Harden says there is nothing of this kind in Washington.

Mr. BURR. A set of papers was given to the first Isthmian Canal Commission in Paris. I am inclined to think that this information was given in the set of papers which was delivered to each member of the old Commission when we visited Paris six years ago.

The CHAIRMAN. Please give the history of the making of this lithograph sheet and blueprint showing cross sections, Mr. Bertoncini. Who made them, and for what purpose and under what instructions?

Mr. BERTONCINI. That profile I made for Mr. Wallace. It was printed at our lithographic office at Panama.

The CHAIRMAN. What does it show?

Mr. BERTONCINI. It was intended to be joined to Mr. Wallace's report. This was connected with that blueprint of quantities, and gives the amount of cubic yards to be excavated according to different propositions.

The CHAIRMAN. You made these computations?

Mr. BERTONCINI. I made those computations; yes, sir.

The CHAIRMAN. What were the data from which you took your figures?

Mr. BERTONCINI. I took them from the cross sections given by the new company.

The CHAIRMAN. You did not take into account anything that has been done by the United States?

Mr. BERTONCINI. These cross sections were made by the last French company when the work stopped. They made a project for the canal with 2, 4, or 6 locks, and they are the sections and profile showing the amount of material to be excavated. On these sections I made the calculations.

The CHAIRMAN. The material the New French Canal Company has taken out since then is embraced in these quantities?

Mr. BERTONCINI. It is shown; it is independent.

The CHAIRMAN (reading): "Work performed by the New Panama Canal Company 10,000,000, 1895–1904; 1881–1889, work performed by the old canal company 48,000,000;" that is a total of 58,000,000 cubic yards. The cross sections on which you made your computations are shown on the margin?

Mr. BERTONCINI. Yes, sir.

Mr. HUNTER. Is this calculated by taking a mean section?

Mr. BERTONCINI. It is taken by cross sections.

Mr. HUNTER. Have you worked this out as an average cross section?

Mr. BERTONCINI. I took it from the cross sections of the land.

The CHAIRMAN. What does that represent, that picture there, is that Culebra?

Mr. BERTONCINI. That upper line means nothing. I have taken profiles from Culebra. I took the whole book of cross sections.

The CHAIRMAN. Book of cross sections? Is it printed?

Mr. BERTONCINI. Yes, sir.

The CHAIRMAN. By whom?

Mr. BERTONCINI. In Paris.

The CHAIRMAN. Has that been among our papers, a book of cross sections? I have never seen it.

Mr. BURR. I do not remember it.

The CHAIRMAN. How many in all?

Mr. BERTONCINI. I have a set in my office of the profiles from kilometer 0 to kilometer 74.

Mr. BURR. What distances?

Mr. BERTONCINI. I think they are every 20 meters (65.6 feet).

Mr. BURR. Throughout the entire line?

Mr. BERTONCINI. Yes, sir.

The CHAIRMAN. There are 50 for each kilometer?

Mr. BERTONCINI. Yes, sir; a book about that high [indicating].

The CHAIRMAN. I have never seen it.

Mr. BERTONCINI. I have it in my office at Panama.

The CHAIRMAN. Fifty cross sections for each kilometer?

Mr. BERTONCINI. Yes, sir. All that was surveyed by the New Panama Canal Company; the whole canal.

The CHAIRMAN. What did it show in respect to deviations, what they call derivations?

Mr. BERTONCINI. Very little difference. Some fillings here and there on the Atlantic side.

The CHAIRMAN. The sections were taken clear across everything?

Mr. BERTONCINI. Yes, sir.

The CHAIRMAN. Do your cross sections treat of anything except the main line of the canal, or do they include the main route of the canal and the derivations also?

Mr. BERTONCINI. They include in some cases the derivations, but generally that is a work apart.

The CHAIRMAN. What have you showing the amount of excavation to be made according to the French project for the derivations. What data have you for that?

Mr. BERTONCINI. In 1896 and 1897 some sections were made on these derivations.

The CHAIRMAN. Have you ever seen a table of French origin of quantities the removal of which were contemplated by the sea-level canal scheme?

Mr. BERTONCINI. Yes, sir.

The CHAIRMAN. You have those figures?

Mr. BERTONCINI. I could find them; yes, sir.

The CHAIRMAN. In Panama?

Mr. BERTONCINI. Yes, sir.

The CHAIRMAN. Did they have the quantities required in the Gamboa dam?

Mr. BERTONCINI. The amount of material to fill it; yes, sir. They had it calculated. Of course for the Gamboa dam there were different projects, and each was a different amount of cubic meters or different amount of material.

The CHAIRMAN. Do you know when the mareograph was established at Naos?

Mr. BERTONCINI. It was at the beginning of 1881; I could not say exactly the date; it was very early.

The CHAIRMAN. You remember one of the sheets in the office that shows Panama Bay and Harbor, and on it are represented curves drawn in blue and red ink, certain lines and arrow marks, the curves representing the currents, the ebb and flow of the tide. Do you remember that?

Mr. BERTONCINI. Yes, sir; I have it in my office.

The CHAIRMAN. That shows a careful study, I think, of the harbor conditions.

Mr. BERTONCINI. Yes, sir.

The CHAIRMAN. Do you know of any report or memorial or monograph on that subject that accompanied that map to explain what these arrow marks are?

Mr. BERTONCINI. These arrow marks of one color show the flood tide when it comes in and the other color shows the direction it takes when it goes out. It is a big map.

The CHAIRMAN. Did you have it copied?

Mr. BERTONCINI. There is no tracing. We could make tracings.

The CHAIRMAN. I think we will have to take this map you have here. We wish also to borrow that one which we speak of. I know you do not want to let it go, but we will have to have it. There was a dike begun on the west bank of the Rio Grande. It rested on San Juan Hill and extended toward the Rio Grande. Was that for controlling the overflow of the Rio Grande or was it for a dam?

Mr. BERTONCINI. It was a proposed dam. It was to inclose a proposed harbor at La Boca. It was to close these little rivers and have the main entrance in front of La Boca.

The CHAIRMAN. Was it intended to close the gap entirely by a dam?

Mr. BERTONCINI. Yes, sir.

The CHAIRMAN. Was it across the Rio Grande to Sosa Hill, intended to go clear across?

Mr. BERTONCINI. Yes, sir; across the whole valley.

The CHAIRMAN. How was the canal to be arranged?

Mr. BERTONCINI. The entrance was to be on a certain part. It was to be dredged to make a port.

The CHAIRMAN. A tidal lock?

Mr. BERTONCINI. They proposed it; it was rather difficult to build it there.

The CHAIRMAN. Did they make any borings across there?

Mr. BERTONCINI. In the direction of the dike?

The CHAIRMAN. Yes.

Mr. BERTONCINI. Borings were made in different places in the whole area.

The CHAIRMAN. On the line of the dike there were none?

Mr. BERTONCINI. No, sir.

The CHAIRMAN. Was there ever any project you know of to place the entrance connecting between Cerro Sosa and Cerro Ancon?

Mr. BERTONCINI. Surveys were made in 1882. It was not continued because there was too much rock.

The CHAIRMAN. This sheet will show the drawings on the axis of the canal down to sea level all through the Rio Grande country?

Mr. BERTONCINI. In this big profile; yes, sir.

The CHAIRMAN. I have a recollection of having heard from you and Mr. Raggi of a plan by Mr. Bunau-Varilla, about building a dam on the head of the Lirio or Obispo; a dam to control the waters of the Obispo.

Mr. BERTONCINI. There was a little dam made that produced these swamps that have been filled in with the dumpings of the Culebra cut. That swamp was made by this dam. They had to make a small diversion to let the water out.

The CHAIRMAN. What was the last plan of the New Panama Canal Company for the disposal of the waters of the Lirio?

Mr. BERTONCINI. It was to go from the Lirio to the Camacho. It had to cross the canal on an aqueduct above, so the ships would pass below it.

The CHAIRMAN. Did not they have a scheme to siphon the water under the canal?

Mr. BERTONCINI. Somebody proposed it; that was during the liquidation.

The CHAIRMAN. How high was that aqueduct to be?

Mr. BERTONCINI. About 20 feet or 30 feet higher than the land is now; that in places is about 50 meters above sea level; that would make it 150 feet or 170 feet high.

The CHAIRMAN. One hundred and seventy feet above the sea?

Mr. BERTONCINI. Yes, sir.

The CHAIRMAN. Were ditches made at Culebra to drain these slopes?

Mr. BERTONCINI. They made them 8 feet or 10 feet deep.

Mr. STEARNS. What was the nature of those shown on the plan that you said were made by the old company?

Mr. BERTONCINI. Small ditches.

The CHAIRMAN. I have seen some that were lined with masonry. Did you bring over any extra copies of this lithograph with you? I think you had better have more sent. You have plenty of blueprints?

Mr. BERTONCINI. Yes, sir.

Mr. BURR. If he has enough, I would suggest that he send one for each member of the Board.

The CHAIRMAN. Is there an extra copy of that book of cross sections you speak of?

Mr. BERTONCINI. I had two or three of the books. This corresponds to the last projects made by the new company, at 9.75, 13.75 and 20.75 meters level. I may have some.

The CHAIRMAN. We want the original or a complete set of these cross sections from which you made your computations. Besides this other data you brought over to-day, what else have you to show that would be interesting?

Mr. BERTONCINI. I brought only these three maps.

Mr. PARSONS. Will Mr. Bertoncini be good enough when he sends these figures to send us the quantities? Could he give us a copy of the quantities?

Mr. BERTONCINI. We can find that in the report of the French commission. Yes, sir; I can give you that.

Mr. PARSONS. You spoke about a book of cross sections you said you had in your office and the quantities for the sea-level canal.

Mr. BERTONCINI. Yes; there is one showing at each 20 meters how much is to be excavated. I could not say if this was the original.

Mr. PARSONS. If you can, look it up and have a copy of that made. If you can, give us the quantities on the whole of the work or between certain principal points, as Bohio, Obispo to Paraiso; give us the grand totals.

The CHAIRMAN. Also the totals in the derivations. Your computations for Mr. Wallace show a bottom width of 150 feet, 175 feet, and 200 feet?

Mr. BERTONCINI. Yes, sir.

The CHAIRMAN. This one shows a bottom width of 150 feet?

Mr. BERTONCINI. Yes, sir. The only difference is the bottom width.

The CHAIRMAN. Do you remember anything about the total amount that the French were able to excavate with each of those excavators of the type of the underdrag, where they dumped into cars—the daily or monthly record of these machines? Have you any recollection about it?

Mr. BERTONCINI. I could not say now. I could find that in my papers.

The CHAIRMAN. If we could get it for a year; I do not mind for a small period, but take one year, 1888 for example, in the Culebra. They stopped in 1889, did they not?

Mr. BERTONCINI. Yes, sir.

The CHAIRMAN. 1888 was a year full of progress, was it not?

Mr. BERTONCINI. Yes, sir.

The CHAIRMAN. Take that year, 1888. Do you know where the figures are to be found showing the total excavation in the Culebra?

Mr. BERTONCINI. I will look. I think I will find it.

General ABBOT. I think those figures are given in the book of Mr. Bunau-Varilla. He was at that time in charge at Culebra. I am quite sure he gives those figures. In the 13,000,000 they took out in one year I think there were only 2,500,000 in the Culebra. Do you remember about that?

Mr. BERTONCINI. Yes, sir.

The CHAIRMAN. Do you remember anything about the average number of days of work actually secured, counting the weather, feast days, and Sundays; how many days' work they actually performed, average through the year?

Mr. BERTONCINI. That can be found; yes, sir. I do not remember at this moment.

The CHAIRMAN. Do you remember how long Mr. Bunau-Varilla was at work with his scheme of dredging the Culebra from a pool formed with the waters of the Rio Grande?

Mr. BERTONCINI. They did not work much in Culebra. The same thing was done in Cascadas; there the ground was more fit for that kind of work, but it was done on a smaller scale because there was not such a big amount to be excavated.

The CHAIRMAN. They floated the dredges there, did they, and put them to work?

Mr. BERTONCINI. No; I mean another scheme; to have big pipes into which the earth was thrown and the water relied on to convey the material away.

The CHAIRMAN. You do not understand. I mean the scheme of bringing the Rio Grande water into the Culebra to make a pool, put a dredge in the pool, dip up the earth with the dredge, and dump it in a car for conveyance?

Mr. BERTONCINI. Yes, sir; that was made; there were two dredges installed with all the necessary machinery. I could not say if it worked well or not.

Mr. BURR. Will those dredges work well where they have to do any blasting in the water?

Mr. BERTONCINI. I suppose it would work best in soft ground.

Mr. BURR. It was not tried except where the ground was soft?

Mr. BERTONCINI. No, sir.

The CHAIRMAN. You are to send me a chart of Panama Bay, the cross-section book, to collect data in regard to the output of these machines per month for one year from active operations, if you can, and you are to send 15 copies of the lithograph sheet with computations.

General ABBOT. I think I can give you some data. They used to make monthly reports to the Comité Technique of the excavation from time to time. I am pretty sure I have a file of them.

The CHAIRMAN. I wanted to ascertain what the effect of rainy weather was upon the French output at Culebra.

General ABBOT. I think they took off 25 per cent of the possible output of an excavator, due to the rain.

The CHAIRMAN. How much was Mr. Choron here?

Mr. BERTONCINI. He came here constantly. He was the chief engineer of the new company.

General ABBOT. You will find a place in his notes where he takes up the question of output and starts in with the full capacity of a dredge and how much it was reduced for various causes, etc.

Meeting adjourned at 4.15 p. m. until October 12, at 9 o'clock a. m.

STATEMENT OF MR. W. E. DAUCHY.

At 10 a. m. Mr. Dauchy appeared before the Board.

The CHAIRMAN. Gentlemen of the Board, this is Mr. Dauchy, the assistant to the chief engineer of the Panama Canal. Mr. Dauchy, will you have the kindness to tell us when you became associated with the canal enterprise as assistant to the chief engineer?

Mr. DAUCHY. I went to the Isthmus in the fore part of November, 1904.

The CHAIRMAN. And from that time on you have been either the assistant to the chief engineer or acting as chief engineer?

Mr. DAUCHY. I went there as engineer of the Culebra division, and at different times during the past year I have acted in the capacity of chief engineer during the absence of the chief engineer from the Isthmus. I never had the title of assistant chief engineer.

The CHAIRMAN. You took charge at Culebra in November?

Mr. DAUCHY. In November, 1904.

The CHAIRMAN. At that time, how many men were at work in the Culebra and about how many machines, speaking in round figures?

Mr. DAUCHY. We had three machines, I think, three or four, one modern American steam shovel, and two or three French excavating machines. As to the number of laborers, I do not distinctly remember the number.

The CHAIRMAN. In round numbers?

Mr. DAUCHY. I suppose we had 700 or 800 men.

The CHAIRMAN. The general instructions that you received from the chief engineer, as to new installations and extension of dumps—tell us in a few words what was the general plan that you were to follow.

Mr. DAUCHY. We had contracted for a certain number of steam shovels, and the general instructions were to prepare for the installation of those steam shovels as rapidly as they were received. The intention was to carry along the preparatory work in the way of track laying, establishment of dumps, and installation of machines, keeping the work done along the different branches advanced as rapidly as the needs of the installation of the new shovels should require. At that time the tracks consisted only of the old French tracks, and they were in very bad condition, and there was a large amount of work required to put those tracks in workable shape, as well as to lay new tracks for the use of the trains waiting upon the additional shovels to be installed.

The CHAIRMAN. During your stay on the Isthmus, up to the time you left, tell us, if you can, the number of machines or units that were used from time to time. That is to say, how did the number increase, and what was the largest number at any time, and was that number of units maintained or decreased?

Mr. DAUCHY. From the time that I first started in November, the number of units was gradually increased up to the 1st of August; at that time we had 11 steam shovels working. In the meantime we had discarded the French machines that were working, but those were discarded gradually, so that I think the total number of units at work showed a gradual increase from November up to August. On the 10th of August, I think it was, the majority of the steam shovels working were put out of service on account of the pressing necessity of doing preparatory work, and not having sufficient labor to carry on the work of preparation and the work of operating the steam shovels at the same time.

The CHAIRMAN. The theoretical efficiency of a steam shovel, of course, is known. What part of that efficiency could you secure, month in and month out, at the Culebra, under the conditions that existed?

Mr. DAUCHY. Well, in working the shovels, the conditions were these: The shovels were the only modern implements we had at work. The locomotives were antiquated, the cars were antiquated, the track was not such as to meet our requirements, and the dumping grounds had not been established in sufficient number, owing to lack of labor with which to establish them, so that the movement of trains was very much congested. We did not approximate anywhere near the rated capacity of the shovels at any time.

The CHAIRMAN. How much effect upon the efficiency of the shovels did the weather have? What was the effect of the dry and rainy weather?

Mr. DAUCHY. Upon the working of the shovels themselves, large and small, it cut but a small figure. It affected very materially the operation of the trains over the tracks, owing to the tracks themselves being constructed in a temporary manner and not built to withstand the effect of the wet weather. I think that with proper track construction and proper preparatory work in the way of track preparation, the effect of the wet weather would be to hinder the work but very little.

The CHAIRMAN. What is the theoretical efficiency of the 2½-yard shovel for ten hours?

Mr. DAUCHY. Those shovels ought to handle 2,000 to 2,500 yards a day.

The CHAIRMAN. And with the proper installation, do you think you could nearly attain that result?

Mr. DAUCHY. No. While that is the capacity of the shovel, that means the shovel working continuously without any interruption on account of train movements, etc., and probably that capacity could never be reached, but in ordinary work, probably 50 per cent of that capacity could be reached.

The CHAIRMAN. You would assume, then, that 1,250 yards would be a reasonable output for a 2½-yard shovel, if all conditions were favorable, and would be affected by the weather to a slight degree only?

Mr. DAUCHY. Yes, sir.

The CHAIRMAN. With your experience at the Culebra in the wet and dry weather, do you consider that a satisfactory installation of tracks, terraces, drainage, etc., is readily attainable?

Mr. DAUCHY. I do.

The CHAIRMAN. Of course, I mean with practical engineering methods.

Mr. DAUCHY. Yes, sir.

The CHAIRMAN. Suppose that there are 100,000,000 yards of earth to be taken out of the Culebra between Obispo and Paraiso, and suppose you excavate below the sea level 40 feet, and allowing that you have all the Isthmus at your command for dumps so you keep clear of the canal itself, also that you could dump in the ocean if you pleased, and consider also that it is important to complete the work as soon as possible—how large a plant would be required? How many units—speaking of the steam shovels—and at what rate could they be installed?

Mr. DAUCHY. I do not know that I understand you, General, when you ask how many units would be required. Do you mean how many could be economically worked?

The CHAIRMAN. Yes. How many could be installed economically on that 7 miles?

Mr. DAUCHY. Well, I think from 80 to 100.

The CHAIRMAN. Of the 2½ and 5 yard type?

Mr. DAUCHY. Yes.

The CHAIRMAN. You would use both sizes?

Mr. DAUCHY. I think so.

The CHAIRMAN. The larger being the more efficient in rock?

Mr. DAUCHY. My experience has been that there is not a great amount of difference in the number of cubic yards handled in a given length of time between the two types of shovels. While the dipper capacity of the larger shovel is greater, still it has necessarily a slightly slower movement, and there is really little difference between them.

The CHAIRMAN. Is the larger shovel more efficient in rock?

Mr. DAUCHY. It will handle larger size rock.

The CHAIRMAN. Is it, generally speaking, more efficient in blasted rock?

Mr. DAUCHY. Yes, sir.

The CHAIRMAN. Eighty to 100 shovels. Suppose, then, it was known that the canal work is to proceed on the basis I have just now stated, and the shovels were sent to you as rapidly as you could make use of them, at what rate could you install them with the necessary tracks and all collateral instrumentalities for efficient work?

Mr. DAUCHY. That depends largely upon the question of labor. If it is assumed that all the necessary labor can be furnished——

The CHAIRMAN. Yes; with that assumption—labor of the same kind you have there now.

Mr. DAUCHY. It would probably take two years before the maximum number of units would be at work.

The CHAIRMAN. With 100 shovels at your command, how many of those would you expect to be in commission every day and how many would be in the hospital—what proportion?

Mr. DAUCHY. Well, of course, as the work advanced, the wear and tear of the machinery would be greater and the laying up for repairs would be more frequent, but I should say that perhaps 6 per cent would be a fair estimate of the number of machines that would be laid up for repairs.

Mr. BURR. Mr. Chairman, I would like to ask whether in naming the 80 to 100 shovels Mr. Dauchy meant that he could keep that number in useful work with a surplus off for repairs, or whether he meant the 80 to 100 included the total?

Mr. DAUCHY. I meant the 80 to 100 shovels would be actually at work. Of course, we would have to have a surplus to keep that number constantly at work.

Mr. HUNTER. If Mr. Dauchy had on the Isthmus 10 per cent additional—instead of 100, say 110—he would hope to keep the whole 100 at work?

Mr. DAUCHY. Yes.

The CHAIRMAN. What is your opinion as to the efficiency to be attained by working at night with electric lights as compared with day work?

Mr. DAUCHY. I think that work could be carried on at night without any great difficulty. It is a question of supplying the lights at the loading and dumping grounds. A certain amount of work, such as track work, can not be done at night.

Mr. RANDOLPH. How would that night work affect the health of the men exposed to the night atmosphere?

Mr. DAUCHY. I do not think it would have any injurious effect. I should think it would be perhaps a little preferable to work at night than at day.

The CHAIRMAN. You have done some night work there in drilling and blasting?

Mr. DAUCHY. Yes.

Mr. RANDOLPH. You do not hold to the old theory that in those countries you should be in the house at sundown?

Mr. DAUCHY. I do not think that a man exercising is subject to any injurious effect.

Mr. RIPLEY. Mr. Chairman, with the number of units at 80 to 100, what would be the labor forces necessary, including track men and dump men?

Mr. DAUCHY. I made at one time an estimate showing the exact number of men required per unit of work, that is for each shovel, but I can not give that number offhand. I think it is on file in the Commission's office somewhere.

Mr. RANDOLPH. Mr. Dauchy, do you increase the number of men per unit over what you would in the United States?

Mr. DAUCHY. Yes. The practical results we have been getting thus far with that labor show that it takes about four men there to do the work of the average workman in this country. We have hoped that the labor condition would be bettered as the number of men increased. The fact of there having been a scarcity of labor has made the labor very inefficient, because they realized that we were dependent upon them, and for that reason they were independent of us and did not do more than they cared to.

The CHAIRMAN. Could you approximate the total number of employees required at the Culebra for a maximum force of 100 shovels—that is, in thousands?

Mr. DAUCHY. I can not give the exact figures, General, but my impression is that it was somewhere about 20,000 to 25,000 men.

Mr. HUNTER. Perhaps Mr. Dauchy could obtain the figures from the office file.

The CHAIRMAN. This report you made was sent in to the chief engineer, and you think he sent it up to the Commission?

Mr. DAUCHY. I think so, but I am not positive.

The CHAIRMAN. After you have finished here, will you see if you can find it?

Mr. DAUCHY. Yes. Of course, in speaking of the number of men required per unit there is this to be considered, that a very large force of laborers is required at once to do the preparatory work. That is to say, if 20,000 laborers were required to operate a certain number of shovels I do not want to be understood as saying that those men are not needed until that number of units are actually at work, because this preparatory work, in my opinion, should be done at once, and a large part of it before any attempt is made to install a large number of working units.

The CHAIRMAN. The preparatory work you refer to consists in general of what?

Mr. DAUCHY. Largely of track laying and the establishment of new dumps. When I speak of track laying I speak of grading and opening up new terraces.

The CHAIRMAN. And drainage?

Mr. DAUCHY. Yes; all those things.

The CHAIRMAN. What is your idea of the steps necessary to be taken to insure immunity from those seepages of water which flow from the upper strata? Give us a general idea of your method of controlling the surface water.

Mr. DAUCHY. I think there is no general plan that will cover all the different cases. There are some of those small streams that will have to be taken care of in the prism of the canal during construction; some, before construction work is carried on to any extent.

The CHAIRMAN. Have you thought of tunneling as one of the methods of drainage?

Mr. DAUCHY. I have thought of it, yes.

The CHAIRMAN. Mr. Dose has given us some figures concerning the output from the Culebra during nearly a year of operations, which I think began in October, last year. He has given it to us by months, and the statement of costs showed very wide differences, ranging from as low as 43 cents per cubic yard up to $1.50 per cubic yard, and he tells us in his statement that a part of that change in cost is due to the fact that at a certain date the number of hours of labor was reduced very largely, from ten hours to eight hours, and the rate of wages was at the same time increased somewhat. Now, what is your idea of the effect upon that work by the change of wages and hours of work which took place, I think, in June?

Mr. DAUCHY. You mean the effect on the increase of cost?

The CHAIRMAN. Yes; the effect upon the unit cost per yard by the change in the rate of wages and the change in hours.

Mr. DAUCHY. I made some figures on it for the month following the change of wages and hours, and as I recollect the increased cost for the month following the change over what it would have been had the ten-hour day and old wages been in effect was 27 per cent.

The CHAIRMAN. Mr. Dose made a statement of similar import to that. I think he made the figure a little higher.

Mr. DAUCHY. I have not it clear in my mind, but it was near 27 or 29 per cent.

The CHAIRMAN. You have stated that you regard the labor available on the Isthmus as very poor, and that rated with the white labor of the northern countries, the Temperate Zone, as about 4 to 1.

Mr. DAUCHY. I did; yes, sir.

The CHAIRMAN. You hope, I believe, that when the laborers are so numerous that there is competition for employment that there will be a better efficiency?

Mr. DAUCHY. It looks to me as though there were only two methods of solving the labor question. One is to flood the country with a sufficient number of the same kind of laborers as

we have now, so that it is absolutely necessary for them to work continuously in order to exist, and the other one is to import a different class of laborers.

The CHAIRMAN. What labor have you had experience with that seems to be available for importation to the Isthmus?

Mr. DAUCHY. I do not know that there is any. I have had in mind the Chinese or Japanese, but I have had no experience with them.

Mr. WELCKER. If night work were resorted to, what would be the increase in the number of laborers?

Mr. DAUCHY. It would practically double the number of laborers in all departments.

Mr. WELCKER. Would it be possible to have that great number of men on the Isthmus—50,000 men at one time?

Mr. DAUCHY. You mean as regards caring for them, housing and feeding them?

Mr. WELCKER. Yes.

Mr. DAUCHY. I think there would be no difficulty in that.

The CHAIRMAN. You speak of doubling the number of laborers for work at night; that would scarcely apply to track work, would it?

Mr. DAUCHY. Yes; because the number of men required for track work is nearly proportional to the traffic over the track. If the traffic was at night it would require an additional force during the day to keep the tracks in proper shape.

Mr. WELCKER. When the installation of 80 to 100 shovels is completed and the work is at its maximum efficiency and the tracks completed and in perfect condition, what does Mr. Dauchy think would be the full number of days of labor per year permitted by the climate? How many working days would be permitted by the climate in a year?

Mr. DAUCHY. You mean how many days out of a year each man will average in a month?

Mr. WELCKER. No, sir. I mean how many days it will be impossible to work on account of rain and other things—great calamities on the tracks, etc.

Mr. DAUCHY. Well, that would be considerable of a guess on my part, but I should say, taking all phases of the wet season into consideration, that a loss of 10 per cent of time would be placing it sufficiently high, perhaps considerably too high.

Mr. HUNTER. Has Mr. Dauchy taken this into account, Mr. Chairman, in his estimate, of the effective value of 1,250 cubic yards a day?

Mr. DAUCHY. With regard to the 1,250 yards per day being the effective output of a shovel, when I made that statement I answered the General's question as to what was generally considered the efficiency of a shovel; that is, under the most favorable conditions. We have always figured down there, in estimating the number of steam shovels required, that when our tracks were installed properly and everything was in condition the efficient output of each shovel would be 1,000 yards per day, counting full time.

Mr. HUNTER. That is, taking 300 days a year?

Mr. DAUCHY. Yes; 26 working days a month, or something like that.

The CHAIRMAN. That means you would expect to do that every day except holidays and Sundays?

Mr. DAUCHY. We would expect to average that.

The CHAIRMAN. Irrespective of weather?

Mr. DAUCHY. Yes, sir.

Mr. HUNTER. That is, 300,000 cubic yards a year per shovel?

Mr. DAUCHY. Yes.

The CHAIRMAN. 30,000,000 a year for the 100 shovels?

Mr. DAUCHY. Yes. Of course, there is this to be considered in counting the number of units at work; there must be a gradual increase to that point, and beyond a certain point there must be a gradual decrease again. You can not figure on working 100 shovels from the time they are installed until the work is completed.

Mr. RANDOLPH. Could you figure on 40 per cent of those shovels?

Mr. HUNTER. What do you think you could average, Mr. Dauchy? I do not see how he is going to answer it.

Mr. DAUCHY. I do not know that I wish to answer it. I do not think that I could give a very intelligible answer, because it so hinges on the length of time it is going to take. I have never made any figures that would enable me to answer it offhand.

The CHAIRMAN. Regarding the average length of track to dump, do you expect to use many of the dumps close by, or rely on those some distance away?

Mr. DAUCHY. Some distance away. The plan that I have always had in mind is to utilize the Panama Railroad as the main means of transportation; that is to say, there will be tracks leading from the cut to the Panama Railroad at as many points as possible, and then there will be tracks leading from the Panama Railroad to dumps at points where it is convenient, and a large part of them will have to be on the Atlantic slope and at a distance.

The CHAIRMAN. Down toward Bohio?

Mr. DAUCHY. Yes.

Mr. BURR. I would like to ask at this point, Mr. Chairman, whether Mr. Dauchy would consider the site of the proposed Gamboa dam as a desirable place for a dump. As a matter of fact, somewhere from 10,000,000 to even 40,000,000 cubic yards of material could be wasted right in that valley. I would like to ask whether he would consider that a desirable place?

Mr. DAUCHY. I would not consider it a desirable place from an economical standpoint. I think the material could be transported to other points and dumped cheaper than it could be at that point.

Mr. BURR. I would like to inquire, Mr. Chairman, what are the disadvantages of that location?

Mr. DAUCHY. Well, in the first place, it is going to require the construction of quite a little track which will be quite expensive construction, and then as the material is deposited in the dam above a certain elevation it will have to be hauled up grade. I have never gone into the question to determine the comparative elevations; that is to say, the amount of material in the dam that would have to be hauled up grade, but speaking offhand I should say there would be quite a considerable amount of it. We have made some attempt to locate a line leading to practically that point from the high portion of the cut, and it is going to require quite extensive grading and quite expensive work to construct a double-track railroad, which would have to be used to handle the material for the dam.

Mr. BURR. The old French company had a dump at that point?

Mr. DAUCHY. Yes; but their dumps were almost all worked on the wrong principle.

Mr. RANDOLPH. Have you made any estimate as to the track mileage that you would need to operate 100 shovels?

Mr. DAUCHY. Yes; we have made those figures.

Mr. RANDOLPH. Are they available?

Mr. DAUCHY. Those figures were made at the same time that I made these figures with regard to the number of men in different capacities. It was something like 200 to 300 miles of track.

Mr. RIPLEY. What height of face of dump can best be worked?

Mr. DAUCHY. I think from 15 to 20 feet, not exceeding 20 feet. I have stated it once or twice at 20 feet. I think the average of 15 feet would be most desirable.

Mr. STEARNS. I would like to know if that answer applies both to rock and earth?

Mr. DAUCHY. In a general way; yes. The dumps of rock can be more advantageously worked at a higher elevation than earth, but I figure that it is not going to be practicable to any great extent to separate the dumps into earth and rock dumps, for they have got to be used for both, and for that reason I do not think it is desirable to establish any dumps over 20 feet high.

Mr. RANDOLPH. Mr. Dauchy, do you consider it more economical to dump and raise track than to build trestles and dump from trestles?

Mr. DAUCHY. I do not think it is economical to dump from trestles. We do not figure on dumping and raising. We start at practically the elevation we expect to maintain and dump alongside, throwing the track over. Heretofore we have not been able to work the dumps with

modern machinery; that is, machinery for unloading material and spreading it from the shoulder of the dump. A large part of that work had to be done by hand.

The CHAIRMAN. What estimation do you place on the value of the locomotives, cars, cranes, hoisting and conveying devices, and other apparatus which the French company used there—I mean its value for future use?

Mr. DAUCHY. I should not place any value upon it, except possibly the locomotives, to the extent that they might be used for switching purposes in a few cases, but I can not recall any cases now where that would be very desirable. The cars I do not think are of any value whatever, and the cranes, while they are good machines, are not at all adapted to the work there.

The CHAIRMAN. Is there any form of American or modern dumping car, English, German, or French, that you think would be valuable there?

Mr. DAUCHY. No, sir. My opinion is that no form of a dumping car is desirable there, where the material is to be handled on the kind of dumps that we have been working. If it is to be dumped into scows to be carried out to sea, a dumping car would probably be valuable; but my idea of the handling of that material is that it should be handled wholly on flat cars and unloaded by scraping it off with ballast unloaders.

The CHAIRMAN. In handling that material in the past, how much of it did you shovel out of the cars?

Mr. DAUCHY. During wet weather we shovel practically all of the clayey material. When it is wet, none of it will clear itself from the car. During dry weather, most of it will clear itself.

Mr. RIPLEY. In wet weather would the clay clear itself from the dipper of the shovel?

Mr. DAUCHY. It always bothered a little by sticking to the dipper.

The CHAIRMAN. The character of the material that you have seen excavated—the rock, for example, the portion of that rock that you would call hard rock, that is in the side of the exposed faces of the Culebra—what portion of it would not crumble when exposed to the air? What percentage of it?

Mr. DAUCHY. Well, of that now exposed I should say two-thirds of it would be considered hard rock.

The CHAIRMAN. Hard rock that you would expect to encounter in widening and deepening the cut? I am discriminating between hard and soft rock.

Mr. DAUCHY. I do not know that I get your idea. Do you mean as to facility of handling it, or in regard to crumbling?

The CHAIRMAN. I will state it another way. Those who have previously estimated on the quantities of material to be taken out in completing the Panama Canal have classified that material as of three kinds—hard rock, soft rock, and earth. Now, the soft rock is that material which at home would be called indurated clay. What I was asking about was the first of those three, the hard rock, not the indurated clay.

Mr. DAUCHY. From that standpoint there would be much less than I said. I think we have made estimates showing that, but I have not got it in mind at present. The great bulk of the material we call rock is soft rock as respects handling it.

The CHAIRMAN. Now, as to the soft rock and the earth, the former being that class of material which generally has to be shot before the shovel can handle it, and the cost of handling that, including the mining expenses, as compared with earth, which of those two materials is the cheaper to handle?

Mr. DAUCHY. Soft rock is cheaper than the clay.

The CHAIRMAN. So that you would really fix a unit price for removing the earth at a figure quite equal to that of the soft rock?

Mr. DAUCHY. Yes.

The CHAIRMAN. With good drainage, would it cost as much to remove the earth as the soft rock?

Mr. DAUCHY. I think it would always during the wet weather. In the dry weather, after we have the facilities for unloading the cars with plows and all that in operation, I think very likely the earth could be handled cheaper than the soft rock.

The CHAIRMAN. As to the stability of that material, soft rock. As you go down deeper and deeper and finally come to the sea level and below the sea level, what slopes, in your opinion, would it be necessary to maintain to insure its stability?

Mr. DAUCHY. I think the great bulk of that would stand on a slope of 1 on 1, and some of it on less than that.

The CHAIRMAN. Could you rely on a slope of less than 1 on 1 in any considerable part of it?

Mr. DAUCHY. Not for any great amount of it. In the higher part of the cut where the question of slope is less material, you could, I think. In the high portion of the Culebra cut you could depend on considerable less slope than 1 on 1.

The CHAIRMAN. In the hard rock portion?

Mr. DAUCHY. Yes.

Mr. RANDOLPH. From the disclosures made by the borings, what is your idea of the rock below, say below level 150—the stability?

Mr. DAUCHY. I think that would stand on a 1 on 1 slope.

Mr. RANDOLPH. You do not think it would be safe to channel the sides practically vertical?

Mr. DAUCHY. I do not think it would be safe for a large part of it. There might be some where it would be safe. A great deal of that stuff is hard, clayey material that disintegrates after exposure to the weather.

The CHAIRMAN. There are certain of those slopes of indurated clay that exist in the Culebra that have stood for years vertical or nearly so?

Mr. DAUCHY. Yes. They are not in the shape, though, to be considered finished work. Pieces drop off occasionally. While in one place they may stand for years, in another they would not stand for months.

Mr. STEARNS. Mr. Chairman, in that connection, I would like to ask whether these movements are movements within a few feet of the surface or in masses.

Mr. DAUCHY. These cases we are talking of now with reference to slope are mostly places that are not considered slides at all. On the slopes that the Chairman speaks of as vertical the disintegration causes a piece to drop off now and then.

Mr. STEARNS. Is that a large piece?

Mr. DAUCHY. No; not in yardage.

Mr. STEARNS. May I ask a further question as to whether there have taken place slides of considerable size in the rock material?

Mr. DAUCHY. I never noticed any slides of any extent. There have been one or two small ones, and those have been mainly where there has been a break in the stratification. Where there seems to be quite a dip or change in the stratification a little slide would take place.

Mr. WELCKER for Mr. GUÉRARD. May I ask, Mr. Chairman, if Mr. Dauchy thinks the soft rock disintegration would be less swift if the slope was very steep?

Mr. DAUCHY. I think probably it would be less. You mean if it were so that the water did not wash on the surface of it?

Mr. WELCKER. Yes.

Mr. STEARNS. Mr. Chairman, in the same line, could Mr. Dauchy give us any estimate as to the amount of disintegration—how fast? Whether it is 1, 2, or 3 feet per year that would slide down into the cut?

Mr. DAUCHY. I could not give you any figures. In the first place it is too irregular; there is no regularity to it at all. As a general rule I do not think there would be any great amount of disintegration if it were finished to an established slope. If the drainage is kept from washing over the face of it I do not think the soft rock would disintegrate very fast.

Mr. STEARNS. The object of my question was to determine the amount of disintegration. If there is not a great deal of it it can be taken care of.

Mr. DAUCHY. My idea of the question of slope is that it must be developed as the work goes on rather than beforehand. Of course, you must start the work with a certain slope, but as the work progresses the proper slope will be found.

The CHAIRMAN. You think it is safe to assume 1 on 1 in soft rock?

Mr. DAUCHY. Yes.

The CHAIRMAN. Take the Culebra Hill by itself. It appears to be massive hard rock. What slope do you think that that could be safely given?

Mr. DAUCHY. I should say 1 on ½.

Mr. BURR. I would like to inquire, Mr. Chairman, whether Mr. Dauchy considers it as significant that the faces have been standing in the Culebra cut for a considerable number of years at slopes that are almost vertical, perhaps 4 on 1. There are slopes, for instance, that in the past six years have stood with very little disintegration. I would like to inquire whether Mr. Dauchy would be inclined to the opinion that the slopes in the same material would be likely to stand to the same extent as the cut progresses?

Mr. DAUCHY. I would say that the question of that material standing on a steep slope would depend largely upon the depth of the excavation. Take an exposed surface there. You may have 15 feet exposed that has stood there for years. Now the question is, if that wall was 200 feet instead of 20 feet, would it still stand?

Mr. BURR. I presume that the question of 200 feet would scarcely arise, but 30 feet or 40 feet might.

Mr. DAUCHY. I should say it was largely dependent upon the depth. That material would stand 10 or 20 feet without any difficulty, but when you get 40 or 50 feet or beyond that, then it would be a serious question in my mind whether the same material that had stood with an exposed face of 15 or 20 feet would stand in the other case.

Mr. BURR. There are some faces there that must have stood in soft rock below the surface clay at least 40 or 50 feet during the half dozen years since I first saw them. In some cases with some small disintegration and in others with almost none.

Mr. STEARNS. I would like to ask him how steep their faces are?

Mr. DAUCHY. Do you refer to the high part of the cut?

Mr. STEARNS. Yes; or in general, whether there are vertical faces or what appear to be vertical faces.

Mr. DAUCHY. I do not think there are vertical faces. Taking into consideration the terraces, I think the slope of the high part of the Culebra cut is about 1 to 1 now.

Mr. STEARNS. Omitting the terraces, about what are the slopes of the parts that seem most vertical?

Mr. DAUCHY. Well, they probably are about 4 or 5 in the bottom bench 15 or 20 feet high.

Mr. STEARNS. About 4 on 1?

Mr. DAUCHY. Yes.

Mr. STEARNS. Are there quite large stretches of what I presume might be considered soft rock with faces at least as steep as 4 on 1 between Emperador and the Culebra Hill?

Mr. DAUCHY. Yes; I think there are some in there.

Mr. BURR. There are places 15 or 20 feet high that run along quite a long distance?

Mr. DAUCHY. Yes; there are such there.

Mr. BURR. Apparently indicating that the greater part of that cut could be classified, probably, as rock, soft or hard?

Mr. DAUCHY. There is more or less rock mixed in it, but there is a good deal of clay there too.

Mr. BURR. Is not the clay a surface covering?

Mr. DAUCHY. Yes; that is true. You soon get below all the clay.

Mr. WELCKER. Mr. Chairman, I would like to ask if Mr. Dauchy thinks that vegetation prevents the sliding?

Mr. DAUCHY. My experience has been the reverse. I have stopped sliding hills by cutting off the vegetation. The weight of the timber on a sliding slope aids materially to assist the sliding.

Mr. WELCKER. Does not the vegetation diminish it?

Mr. DAUCHY. If you could get a grass-covered slope it would help to diminish it.

Mr. RANDOLPH. Mr. Dauchy, there are cross sections available for all that work?

Mr. DAUCHY. Yes; they are on file in the Commission's office.

Mr. RANDOLPH. How long have they been there?

Mr. DAUCHY. At the time Major Harrod and General Hains were down there they brought them back with them.

The CHAIRMAN. For the purpose of estimate, what would you regard as a safe figure to take as the cost of the earth, soft rock, and hard rock, including contingencies and all expenses such as a contractor would encounter if he were doing the whole thing?

Mr. BURR. That is for the Culebra cut?

The CHAIRMAN. Yes; the Culebra cut.

Mr. DAUCHY. Do you mean dividing it into classification, or an average price?

The CHAIRMAN. Either way; if you can divide it, so much the better.

Mr. DAUCHY. You do not mean to include in that any expense for sanitation or administration?

The CHAIRMAN. No; not general administration such as at Washington and the city of Panama. Suppose a contractor had agreed to remove the Culebra cut and deposit it at proper places and incurred all the expense, charging in the plant as a part of the cost.

Mr. DAUCHY. I think from that point of view that Mr. Wallace's figure of 50 cents per yard would be a fair basis. While it has cost us at times a great deal more than that, it has been because we have not had the preparatory work necessary to handle the material in an economical manner and have worked mostly with an antiquated plant. We have reduced it to that figure, and considerably below under favorable conditions, even with the adverse plant we were working with, and I think that with a modern plant and a proper amount of preparatory work 50 cents per yard would be a fair figure.

The CHAIRMAN. That includes the cost of plant?

Mr. DAUCHY. Yes; and preparatory work. Of course, the first cost would be large, but distributing the cost of installation through the entire yardage, that would be a safe figure.

Mr. RANDOLPH. With the eight-hour law?

Mr. DAUCHY. That is a feature that I had not considered.

The CHAIRMAN. If a contractor were doing the work the eight-hour law would not bother him. The contractor who is erecting the bridge over Rock Creek in this city works his men ten hours or more.

Mr. DAUCHY. I should say those figures were all made on a ten-hour basis, and I think the figures should be increased by the cost essential to an eight-hour law, or probably 25 per cent.

Mr. HUNTER. Ten hours as compared with eight hours is 20 per cent, is it not?

The CHAIRMAN. Would that increase the reasonable margin of contractor's profit?

Mr. DAUCHY. No; we figured that as the actual cost.

Mr. WELCKER. Does 25 per cent include pumping expenses?

The CHAIRMAN. Does that include drainage?

Mr. DAUCHY. Yes; all costs of removing the material.

Mr. STEARNS. For a sea-level canal?

Mr. DAUCHY. Yes.

Mr. BURR. Mr. Chairman, I would like to recur once more to the subject of the Gamboa dam, because it affects the estimate of cost. I would like to inquire of Mr. Dauchy whether if the maximum elevation of the dam was limited to 180 feet above sea level, and if the amount did not exceed, we will say, 10,000,000 cubic yards or even 5,000,000 cubic yards, whether that amount of elevation would entail any cost in excess of that which would be involved in wasting the material at a desirable dump?

Mr. DAUCHY. Yes; I think it would. I do not know as I understood exactly, but if it was decided to build the Gamboa dam and it came to be a question whether the material should be taken from the Culebra cut or elsewhere, it would probably be cheaper to take it from the Culebra cut; but considering the question of the removal of material from the Culebra cut by itself, I think it could be deposited cheaper somewhere else than at the Gamboa dam site.

Mr. BURR. Can you give us any estimate of the extra cost of dumping per cubic yard for the Gamboa dam site over that at better dumps?

Mr. DAUCHY. No; I never have figured on it.

Mr. BURR. Would that extra cost exceed 15 or 20 cents a yard?

Mr. DAUCHY. Yes. If the material were limited to the amounts you mentioned, I think it would, because the cost per yard would depend largely upon the bulk that was handled. If it were a question of 20,000,000 or 30,000,000 yards it would be different. You have to build your railroad the same whether it is 5,000,000 or 30,000,000 yards.

Mr. STEARNS. Would you be able to use the same railroad for the low levels as for the high?

Mr. DAUCHY. To build a piece of railroad to economically handle the material from the Culebra cut to the Gamboa dam site you would have to start pretty well up toward the top of the Culebra cut and follow the contours to reach a location where you could dump your material. That piece of track would not be accessible for transporting the material between the high parts of the Culebra cut and Obispo. You could not get to that piece of track without clearing—it would not be an economical piece of track to operate for the purpose of carrying away material from the cut, whereas on the other side, utilizing the Panama Railroad, which drops about uniformly with the bottom of the canal, so that you can come out of the canal at different levels, say elevation 90, 120, and 150, and so on, right to the Panama Railroad, without hauling your material up grade. This condition of affairs does not exist on the east side of the canal, and you can not very well create it there. With reference to depositing the material in the Gamboa dam, after you nearly reach the dam site you must haul your material up grade.

Mr. STEARNS. Would it be feasible to deposit the material in the base of the dam from such a high road, or would it be necessary to come in on several levels?

Mr. DAUCHY. I presume it would be economical to have at least two different tracks, one at a high elevation and one considerably lower.

Mr. RANDOLPH. Mr. Dauchy, have you any estimate as to the cost of building a double-track railroad through that section of the country, on such grades as you would adopt for this work?

Mr. DAUCHY. Do you mean to the Gamboa dam site?

Mr. RANDOLPH. Yes; or through any section of country.

Mr. DAUCHY. You can hardly set a price per mile of track, the conditions are so varied. This Gamboa railroad—we will call it the Gamboa railroad—to the proposed site of the Gamboa dam would be the most expensive piece of track that we have had under consideration.

Mr. RANDOLPH. You are familiar with the maps showing the proposed change of location of the Panama Railroad to go around the proposed Bohio Lake; what is your idea of the cost of that road per mile?

Mr. DAUCHY. That is a question I have never looked into.

Mr. RANDOLPH. To make the Panama Railroad available for this work it will be necessary to double track it.

Mr. DAUCHY. All except possibly 4 or 5 miles on the summit.

Mr. RANDOLPH. You have the old Panama Railroad.

Mr. DAUCHY. That does not help the situation. The great bulk of the material taken from the cut will strike the Panama Railroad at a point at least 2 or 3 miles from the summit, so that 5 or 6 miles over the summit will not be used for transporting the material from the cut. From a commercial standpoint it is a question whether we ought not to double track the whole length to facilitate the handling of freight, but for canal construction I think there is a stretch of 5 or 6 miles covering the summit that need not necessarily be double tracked.

Mr. WELCKER. Mr. Chairman, Mr. Guérard asks if you could give an approximate estimate of what would be the cost of doubling the track of the Panama Railroad from Panama to Colon?

Mr. DAUCHY. There are figures on file in the Commission's office giving that.

Mr. NOBLE. Mr. Chairman, do I understand Mr. Dauchy to say that a force of approximately 20,000 or 25,000 laborers would be required in connection with the work of the Culebra cut?

Mr. DAUCHY. Those are the figures I gave. As I stated at the time, I made a careful estimate giving the exact number needed for each unit, and while I do not recall the exact figures now it is my impression that it is somewhere in that neighborhood.

Mr. NOBLE. Does that include night work?

Mr. DAUCHY. No; that is just for day work.

Mr. NOBLE. Would that force have to be approximately doubled for night work?

Mr. DAUCHY. Yes.

The CHAIRMAN. The chief engineer has sent to the Commission certain figures on that matter. I think I recall a conversation with him, when he stated he thought a maximum of 30,000 laborers would be required.

Mr. DAUCHY. It is hard to figure on the exact number of laborers required. The labor we have at the present time is very inefficient. It seems to me almost a necessity that more efficient labor be obtained; and if that is obtained, of course it makes quite a difference in the basis of figuring as to the number of men needed. The figures have been made on the basis of the kind of labor that we have at the present time. What seems to me to be the most essential thing in the question of preparatory work is the obtaining of a more effieient class of labor than we have at present.

The CHAIRMAN. Bearing upon that is also the well-known fact that labor imported to the tropics from a colder climate will be subjected to climatizing vicissitudes, impairing their efficiency.

Mr. DAUCHY. Take the question of cost, what we are paying for that labor, regarding its efficiency, makes it the most expensive labor of its kind that I ever saw or heard of in the world. It is practically equal to paying the ordinary day laborer in this country $4, $5, or $6 a day.

Mr. NOBLE. That is essentially the same kind of labor that was used in Nicaragua, Mr. Chairman?

The CHAIRMAN. Yes.

Mr. NOBLE. And reports concerning that labor were quite satisfaetory, I think?

The CHAIRMAN. I believe so.

Mr. DAUCHY. I think they pay that same class of labor in Jamaica much less than we are paying on the Isthmus.

The CHAIRMAN. In Jamaica there is a negro population of 700,000 and there is a constant struggle for existence. Half of them have inadequate subsistence. When they built the railroad in Jamaica, there was a throng rushing for work, ten times beyond the needs, and the contractor would retain only the efficient.

Mr. DAUCHY. I think the average price of labor there is about a shilling a day.

The CHAIRMAN. That is about the average.

Mr. DAUCHY. There seems to be not the least ineentive on the part of the Jamaican laborer to accumulate, and if he can earn enough in one or two days to keep him a week, he would rather do that than to put in full time.

Mr. PARSONS. Is Mr. Dauchy willing to take that ratio and apply it to his estimated cost price; that is, an estimate of 4 or 5 to 1? Does he think that the Culebra cut would cost 10 cents a yard here?

Mr. DAUCHY. Well, there are other elements that enter into it besides the price that is paid the cheaper kind of labor. Our gold pay rolls amount to a large proportion of the expenditure made. There is no question in my mind but what the canal could be built much more cheaply here.

Mr. HUNTER. I think Mr. Parsons is rather exaggerating.

The CHAIRMAN. Do you think the Government should feed that labor, or should they be left to feed themselves?

Mr. DAUCHY. I have always been favorably inclined toward the idea of the Government doing it, for the reason that the men, when they furnish their provisions, do not as a rule furnish the class of provisions that men doing that kind of labor require, and I have thought that if the

Government furnished them with provisions of the proper kind that they would be more physically able to do a good day's work than under the present conditions.

The CHAIRMAN. Has your opinion undergone a change?

Mr. DAUCHY. Well, it would be somewhat of an experiment. I do not know that it would work out as I figured it.

The CHAIRMAN. Were you satisfied with the Government methods in attempting to feed the laborers there during April and May?

Mr. DAUCHY. They were not carried on to an extent to demonstrate that point. We only fed the recent arrivals for a few days until they made other arrangements. There would be one or two advantages. The question of delayed pay days has cut quite a figure in getting work accomplished, and if the men were fed it would be immaterial as to the frequency and regularity of pay days.

The CHAIRMAN. How does the rate of wages paid to the gold men—men from the United States—compare with the wages paid in the United States to the same class of men, clerks, laborers, timekeepers, steam-shovel men, blacksmiths, mechanics, etc.?

Mr. DAUCHY. I think it averages about 40 per cent above that of the same grades of labor in the United States.

Mr. STEARNS. Is that enough to get efficient men?

Mr. DAUCHY. Well, I do not know that I can answer that. A good many men that have been sent down there have not been efficient. Whether it is due to the fact of small pay or not is a question I can not answer. Some are efficient, some are not.

The CHAIRMAN. Considering the disadvantages, the fact that the Government pays the outward passage and the salary from the time the man leaves New York, and considering the number of failures that result, or have so far resulted—basing your opinion on your experience, would 40 per cent cover the increase that the Government pays for labor on the Isthmus?

Mr. DAUCHY. No; I do not think it would. But I figure that the salary a man receives there is about 40 per cent above what he would receive for performing the same services in the United States.

The CHAIRMAN. Take the net result of the total labor employed, and charging up against it all the expenses the Government incurs in getting it down there, would it not be nearer 50 per cent?

Mr. DAUCHY. I think the experience thus far would show that it had been; but I do not know that that is a fair basis to figure on in the future, because a force will gradually accumulate there that will settle down and perform the work. Heretofore there have been men sent down who were not competent, some who have been discouraged, and others who merely wanted a trip.

The CHAIRMAN. In the United States would a steam-shovel man, fireman, or timekeeper receive six weeks leave on full pay?

Mr. DAUCHY. No.

Mr. STEARNS. Does not that increase the sum?

Mr. DAUCHY. Oh, yes; probably. When I answered the question I did not understand that it was intended to cover the total outlay of the Government. I referred merely to the relative price of wages there and here. I never figured it on that basis, and I would not want to say just what that would be.

The CHAIRMAN. When the canal is finally finished all those expenses are to be finally charged against the canal, and they are properly a part of the labor item. Are there any more questions, gentlemen?

Mr. STEARNS. I have noted one or two, Mr. Chairman. I was not here at the first part of the hearing, and if any of them have been already answered, perhaps some of you gentlemen will stop me. One question is as to whether in estimating the amount of delay and the number of steam shovels out of use, the effect of slides has been taken into account, or is it assumed that the slides can be prevented in the future.

Mr. DAUCHY. I think that the question of slides can be eliminated after the first year or two of work, provided it is carried on with that end in view. The material that slides forms a small percentage of the total amount of material to be removed; it seems to me almost insignificant when compared to the total amount to be excavated, and while it has bothered a good deal thus far, by a proper direction of work toward the removal of that sliding material as soon as possible, I think it can be gotten out of the way so early that it need not be considered.

Mr. STEARNS. Would not that make some additional percentage if the work was being done in terraces and even a small slide should come down on one slope and interrupt the tracks?

Mr. DAUCHY. I do not think that is likely after the first removal of the material.

Mr. STEARNS. The question has been asked about the slopes in rock above water; I was not here when any questions were asked as to how that material would stand in water. For instance, supposing it were desired to excavate the rock very nearly vertical below the water level in the canal, I do not want to know what the effect of waves on it might be, but down where it is still water, whether it stands or dissolves?

Mr. HUNTER. Mr. Dauchy might take that as 5 feet below the surface.

Mr. DAUCHY. My observation has been that the lower you get in excavation the harder that material becomes, and I have always thought and still think that when you get to some depth, particularly as we approach sea level, that the material will stand without any dissolution in the water. I think it would be desirable, however, always to provide for a berm above the surface of the water, perhaps anywhere from 5 to 10 feet above the surface of the water before the slope above that is carried up any farther. I do not know whether I make myself clear.

The CHAIRMAN. Yes; we understand.

Mr. STEARNS. I would like to ask the purposes of the berm?

Mr. DAUCHY. If there is a disintegration of this material it takes place only to the height of that berm and is not liable to cause a slide. To prevent the disintegration of the bank immediately adjoining the water would be another purpose.

Mr. STEARNS. Supposing this berm were not provided and the rock were sloped 1 on 1, what effect would be had if it washed away the toe of the slope? Would it, in your opinion, weaken the whole structure so that it might slide for 200 feet above?

Mr. DAUCHY. I think it would. If it washes away I think it might rapidly fall in.

Mr. STEARNS. Taking a large mass?

Mr. DAUCHY. I think so.

Mr. STEARNS. In that vertical face under water, below the wash of the passing ships, could that vertical or nearly vertical face be as high as 40 feet?

Mr. DAUCHY. I should not say so with reference to all materials. I should not advocate putting a vertical face in what we consider soft rock if that material exists at the final elevation of the water.

Mr. STEARNS. I was assuming that there would be no wash down below this 5 feet.

Mr. DAUCHY. I do not know that I expressed myself properly in regard to washing, but what I mean is the material adjacent to the water, whether it is still water or other.

Mr. STEARNS. If the walls were nearly vertical below the water, would you regard retaining walls of concrete or masonry necessary?

Mr. DAUCHY. In certain materials I would. It looks to me as though the question of what the final material is going to be, particularly if it goes to sea level, is quite problematical. My opinion is that most of that material would be of such a character that it would stand on a slope of 1 on 1, but I doubt whether the majority of it would be of such a character as to stand vertically.

Mr. BURR. Mr. Chairman, it might be mentioned here as bearing on Mr. Stearns's inquiry, that pits, some five or six in number, made by the new company, and which were kept open for a number of years, all filled with water until the original Isthmian Canal Commission visited the Isthmus, when they were pumped out, showed no effect of deterioration by the presence of water. The water stood in some of them at depths of not less than 30 or 40 feet. I was in one of them

myself and I think Mr. Noble was in another. The water standing in those pits at that time caused no disintegrating effect. It seems to me a peculiarity of that place.

Mr. RANDOLPH. Professor, to what depths did those pits go?

Mr. BURR. Those pits went down to an elevation of about 35 to 40 feet. They were 1 meter in diameter.

Mr. NOBLE. There were places where pieces of indurated clay were broken off, but the material itself was firm and there was no surface disintegration, just as Professor Burr has stated.

Mr. BURR. You could pick off pieces with your hand.

Mr. NOBLE. I brought up some samples and after it was dried thoroughly it was very active when put again into the water.

Mr. BURR. If it is dried and put into water it is very active. That which we called soft rock goes to pieces, mostly; the hard rock will not.

The CHAIRMAN. Those pits were dug from the bottom of the 60-foot level, were they not?

Mr. BURR. I think so.

Mr. STEARNS. I do not know whether Mr. Dauchy can answer this or not, and it seems almost the same question he has answered, but I am rather desirous of getting his opinion as far as possible as to what the nature of the sliding on the side of the cut would be where it is, say, 200 feet deep, if it were eroded. Supposing the sides were left so nearly vertical as to be 8 vertical to 1 horizontal, almost entirely vertical, and 200 feet high, would you expect a great mass of that rock on some weak seam to slide out?

Mr. DAUCHY. If sliding took place, I would.

Mr. STEARNS. Or would you expect that only portions of it would tumble off from time to time, and not a great mass running back 100 or 200 feet?

Mr. DAUCHY. If it were in the nature of a slide, I would expect a large mass of it to come down. If it is a question of disintegration, then it would come down in smaller chunks.

Mr. STEARNS. The question is as to the liability of slides if it were nearly vertical.

Mr. DAUCHY. Well, all slides that I have seen have acted in that way. Of course, if the material is fairly uniform so there is no weak point in it, it may come off in larger or smaller chunks. If there is a weak point that is probably the point where it would break.

Mr. STEARNS. I have here a sketch showing a prism of a section of the canal with 1 to 1 slopes down to a berm and vertical sides below that to the bottom of the canal. Assuming that the wash of the waves were to gradually destroy that berm and undercut the toe of the 1 to 1 slope, would there be merely a breaking down of comparatively small quantities, on somewhat nearly vertical lines, or would there be a slide on some line parallel to the slope which would let a great mass down? I do not know as that question can be answered.

Mr. DAUCHY. I could not answer it, I am sure. I think at times there would perhaps be large masses coming down.

Mr. STEARNS. The other question I had is entirely outside of the subject, but we have learned very little as to where sand may be obtained for masonry, and as to whether there is any good sand in the Chagres River above or below Gamboa. Can we get any light on that subject as to whether it is obtainable there?

Mr. DAUCHY. The most available sand is the beach at Panama. We utilize that and also take some sand from pockets that originally came from the same place and had been used by the Panama Railroad in widening and for banks, etc., but that is practically the only sand we have been able to use.

Mr. RANDOLPH. Is that a good quality?

Mr. DAUCHY. Yes; very good.

Mr. STEARNS. How much is there?

Mr. DAUCHY. I should say there is an unlimited amount of it, a very large quantity.

Mr. BURR. Have you tried any sand from the Chagres River?

Mr. DAUCHY. No; I have no doubt that there may be pockets of sand found in the Chagres River, but my experience with river sand has been that you can not get it in very large

quantities and it is usually mixed in with alluvial matter. If not that, it is usually a kind of gravel that you have to sift. There is a gravelly bank with a good deal of sand in it.

Mr. STEARNS. Is there clay mixed in with it or alluvial matter?

Mr. DAUCHY. I think there would be both in spots. I do not think you could take it out continuously and get pure sand.

Mr. HUNTER. Could you not wash it?

Mr. DAUCHY. Possibly, but you could get sand from the beach cheaper than to wash it and sift it and cleanse it.

The CHAIRMAN. Mr. Boyd Ehle told me that he thought those gravel bars around Matachin could be taken out by a steam shovel and would be suitable for concrete without further admixture of sand.

Mr. DAUCHY. Undoubtedly portions of it would, but I do not think you could load it with a steam shovel properly. Undoubtedly there are portions of it that would be good, but as to an amount I am rather doubtful.

Mr. HUNTER. Are there not very large pockets?

Mr. DAUCHY. Examining the nature of one of those gravel bars you will find perhaps on one edge of it more or less sand mixed with alluvial matter. Farther in you will find what I call a pocket of clear, pure sand. Then possibly beyond you may get a place where there is more or less alluvial matter. It has stopped or mixed, and you will not find the pure material in uniform distribution.

Mr. HUNTER. Is not that only a case of washing it?

Mr. DAUCHY. Probably.

Mr. HUNTER. How much per cubic yard would that cost the company?

Mr. DAUCHY. Well, I can not say, because I am not enough familiar with it.

Mr. HUNTER. At the very worst would it be half a dollar a cubic yard?

Mr. DAUCHY. No; but we could get it from the beach for less than 50 cents a yard.

Mr. WELCKER. In the name of Mr. Guérard, I would like to ask Mr. Dauchy where are located the sand banks at Panama?

Mr. DAUCHY. It is right along the main shore. I do not know that I could give directions, but it is east of the old pier, right on the shore of the bay, east of the old railway pier.

The CHAIRMAN. It has been a favorite beach from which has been taken all the sand to build the city of Panama and all that the railroad company used and all that has been used by the Isthmian Canal Commission, the French company, and everybody else. They have all resorted to that beach. Mr. Maltby told us, or the other young man who is his assistant, of one of those beaches near the mouth of the Farfan River, on the west shore of the Rio Grande, where there is a great abundance of sand.

Mr. STEARNS. Have you some idea as to how much that sand would cost per cubic yard delivered at a point on the railroad?

Mr. DAUCHY. Do you mean loaded on cars there or for transportation?

Mr. STEARNS. Transportation. To be used mainly for the locks in a lock canal, I presume, and large quantities would be required.

Mr. DAUCHY. I think that sand at the outside figure could be delivered anywhere along the Panama Railroad for 75 cents a yard.

Mr. RANDOLPH. That is cheaper than we get it in Chicago. It costs $1.25 there on the works.

Mr. DAUCHY. Where do you get it from?

Mr. RANDOLPH. Bank sand.

Mr. DAUCHY. Well, you can get it very cheaply there. It is merely the cost of transportation.

Mr. PARSONS. Mr. Chairman, I should like to hand Mr. Dauchy some figures that Mr. Dose gave us at Colon showing the total number of cubic yards for eleven months, from October last to August, both inclusive, together with the average cost for those yards, and then the distribution of the cost for the month of March, which is the cheapest month, and the month of August, which

is the most expensive month, and then the average for the whole eleven months, and ask Mr. Dauchy if he can throw any light upon those figures.

Mr. HUNTER. Perhaps Mr. Dauchy will answer the question better if he can consider the figures quietly and put the answer in writing after lunch time.

Mr. DAUCHY. I do not know, Mr. Parsons, that I understand these figures exactly. This is distribution of cost?

Mr. PARSONS. Yes.

Mr. DAUCHY. I can answer the question offhand as to the minimum and maximum months. There is a distinct reason for that.

The CHAIRMAN. Can you answer now or would you like to take time?

Mr. DAUCHY. As long as there is to be a further consideration of the matter I will answer it after lunch, I think.

Mr. RIPLEY. Will it be desirable to have the actual wages paid for different classes of labor?

The CHAIRMAN. I hardly think so, there is a very large number.

Mr. DAUCHY. That is all a matter of record in the Commission's office.

At 12.10 o'clock Mr. Dauchy was excused to appear again before the Board at 2.30 o'clock.

The Board reconvened at 2.30 p. m. with Mr. Dauchy present.

The CHAIRMAN. Mr. Dauchy, you were to make a search for some data. Will you tell us what you have found?

Mr. DAUCHY. Referring to the number of laborers needed to operate 100 steam shovels, I found the figures in the office downstairs. The total number of men needed for the 100 shovels was practically 24,000, of which 20,000 were common laborers.

The CHAIRMAN. That is for a day shift?

Mr. DAUCHY. Yes. A copy of that estimate which goes into details of the different classes of men can be obtained downstairs.

The CHAIRMAN. Should the Board care to see that paper which gives in detail the estimate which Mr. Dauchy has just referred to, the number of men in each class and the rate of wages—is it very long?

Mr. DAUCHY. It is easily copied.

The CHAIRMAN. The Secretary will please obtain a copy at his leisure. (See pp. 340–345.)

The CHAIRMAN. What was the other matter?

Mr. HUNTER. The explanation of the maximum and minimum cost.

Mr. DAUCHY. Taking the figures by months, the cost gradually decreased from the beginning of the dry season until the month of March, in which the figures were the lowest. Commencing in December, the organization was planned to provide for the installation of a certain number of shovels each month and the carrying out of that plan was entirely dependent upon the number of laborers obtained, and at the time the plan was made it was supposed a sufficient number could be obtained to meet the requirements as the shovels were installed. The supply of laborers did not increase anything like the proportion in which they were needed. In the meantime other classes of labor had been obtained—that is to say, mechanics, track men, and others of that kind—and the situation at the end of the dry season was that we had an expensive organization, and the preparatory work to operate that organization had not been completed. As the yardage was not increasing and the rainy season approaching with the preparatory work not completed, the result was that as soon as the effect of the rain was felt the bad condition of the tracks caused numerous derailments daily, and these derailments of course blocked the whole work. In a very large piece of work the economic operation of one department is entirely dependent upon the others; if anything occurs to block the operation in one department it blocks the whole work.

Another reason for increased expense when the rains came on was the fact that we were handling the material with the old French dump cars and on dumps that were very high. The new dumps as planned had not been established. A large proportion of the material that was being taken out during the wet season had to be unloaded by hand; that is to say, the dump cars would not clear themselves and the material had to be shoveled off. Had we had flat cars with

the machinery for unloading I think the moving of that material could have gone on at the same low cost for which it was handled during the dry season. The large difference between the lowest cost in March and the maximum cost in August resulted because the moving of material was practically stopped on the 10th of the month of August; that is to say, most of the shovels were put out of commission and with those that remained in use, the excavating of material was a secondary matter; they were working for the purpose of shaping up the cut and not with reference to getting out a large yardage. When the working of the shovels was stopped in August, the expensive organization was practically the same as before, although it was reduced to a certain extent by letting out a number of train men. Still the cost of the organization was practically the same as it had been before; that, with the largely decreased output, made the unit cost jump up somewhat.

The CHAIRMAN. Did not a part of the increased cost arise from the fact that the hours of labor had been reduced?

Mr. DAUCHY. Yes. That took effect in June, and the month of June shows a material increase in the cost of output over the month of May, although the rise is quite gradual from the month of March up to June, increasing every month as the effects of the rain were more felt.

Mr. PARSONS. What were those figures, March, April, May, and June?

Mr. DAUCHY. Commencing with March, 43.28 cents; April, 52.47 cents; May, 83.80 cents; June, 102.74 cents.

Mr. PARSONS. The increase from May to June was about 25 per cent; about equal to the reduction in hours?

Mr. DAUCHY. Yes. As to the detailed unit cost—that is, the manner we have kept them charged, loading dumps, and so on—it is hardly fair in the matter of comparison to take these individual costs, that is the increase in these specific costs, as a criterion in the increased expense of that particular department, because anything that stops the work in one part immediately increases all of the unit costs. For instance, take the cost of track maintenance, it is all upon a yardage basis and anything that stops the output would show a vast increase in the cost per yard for track maintenance, while the total cost might not have increased at all. All the unit costs are upon a yardage basis.

Mr. PARSONS. Have you any figures in Washington that can give us an estimate as to the delays that took place due to derailment?

Mr. DAUCHY. I can say in a general way that after the rainy season set in we had an average of 12 to 15 or 20 derailments daily.

Mr. PARSONS. Could these derailments have been prevented if you had had a satisfactory track?

Mr. DAUCHY. To a large extent. They were mainly due to the poor track condition and also due to the equipment that we used. Take the French dump cars. I found upon investigation that the wheel gauge of these cars varied in almost every individual car. You take a train of these cars and hardly any two cars had exactly the same wheel gauge. We found cases where the two pairs of wheels under a car were of a different gauge, so the derailments were partially due to that cause.

Mr. PARSONS. Three causes, I presume—bad track, bad equipment, and bad soil. The bad soil was dependent entirely upon the weather. In your judgment what proportion of derailments was due to bad track and bad equipment and what proportion to the soil?

Mr. DAUCHY. It is hard to distinguish between bad track and bad soil, because where there is bad soil there is bad track. In order to put the track in condition I should consider it necessary to ballast it.

Mr. PARSONS. That is to say, with a proper track you could have got over the difficulties of bad soil?

Mr. DAUCHY. Yes, sir.

Mr. PARSONS. During the dry season, what proportion of the time were your shovels at work? I remember seeing some statements that shovels were working for only two or three hours a day. Can you give us the actual figures?

Mr. DAUCHY. I can not give you the actual figures. You are about right in your statement. Perhaps two hours a day.

The CHAIRMAN. I have heard it said that some of the derailments of engines were due to inflexibility of the frame of the engine—its lack of conformability to the inequalities as the engines passed over the track. With a more flexible frame and mounting, would you have had less derailments?

Mr. DAUCHY. That is true. A very large amount of the increased cost was due to the trouble of dumping the material; not only the dumps getting in such shape, but every train having to be unloaded by hand.

Mr. PARSONS. What would you recommend?

Mr. DAUCHY. I would recommend a dump varying in height from 12 feet to 20 feet, with the use of flat cars with Lidgerwood unloaders.

The CHAIRMAN. If I am not mistaken, one cause of derailment was the fact that the rail of French section used in that track was thought by the engineers to be too high in proportion to its base.

Mr. DAUCHY. Yes; that was one great trouble. The Belgian rail in use was 4⅝ inches in height and 3¾ inches wide base, and at the time most of the tracks were laid we had no tie plates to put under. This rail was laid upon soft-wood ties, a portion of the time with very short spikes, so it was impossible for the rails to stand up.

Mr. PARSONS. In the figures you have quoted, the average cost for eleven months is 58 cents?

Mr. DAUCHY. 58.6 cents.

Mr. PARSONS. For three months the Commission was paying its men on the basis of eight hours a day; for the other eight months paying ten hours a day. You have stated the average cost would be reduced to 50 cents a cubic yard. Making the reduction for the three months and assuming ten hours a day, the average for the whole year would have been about 55 cents per cubic yard.

Mr. DAUCHY. Would not it have been less than that? The three particular months, June, July, and August, the expense per yard was so much higher?

Mr. PARSONS. The yardage was much smaller than the other months. It would not make much more than that. It would take it to 55 cents. Your statement of reducing it to 50 cents would involve a reduction of some 10 per cent. I judge from the remarks you have made that with a proper track and proper equipment you would make a greater saving than 10 per cent.

Mr. DAUCHY. Yes.

Mr. PARSONS. I would like to ask if you consider it entirely feasible from your experience on the Isthmus to provide such plans and tracks as will practically obviate these difficulties which you have described?

Mr. DAUCHY. I do; yes, sir.

Mr. PARSONS. Referring to the explanation that the yardage cost was increased on account of the shaping up of the banks and the laying of the roads leading to the dumping ground, I would like to ask if that was excessive for the period of eleven months over what it will be with reference to the entire work? That is, a certain amount of that shaping up, the changing of the grade, and relaying the roads must be done for the entire cut. What can you say about that?

Mr. DAUCHY. That is, you refer to the small output per unit on account of using the shovels to shape up for tracks in proportion to the whole amount taken out? I should state that the proportional amount of that kind of work was larger during that time than it would be after we had installed a greater number of units. If we had 50 steam shovels working and out of that number 5 were working with reference to shaping up the cut or developing the cut for new tracks, the percentage would be smaller than if we had 10 or 15 shovels working and 5 working with the same object in view.

The CHAIRMAN. A certain expenditure will have to be made for shaping up the banks and also for relaying the tracks leading to your dumping grounds.

Mr. DAUCHY. I should say the proportion of that work during the past year is much greater in proportion to the total output than it would be in the future after a large number of units had been put at work.

Mr. RANDOLPH. How large an auxiliary plant would you estimate as necessary? What number of cars for each shovel?

Mr. DAUCHY. Those figures, Mr. Randolph, are all given in the statement you are asking a copy of. I can not give them offhand.

Mr. RANDOLPH. Is that a statement we will have copies of, Mr. Chairman?

The CHAIRMAN. Yes; the Secretary will obtain them. Any other questions?

Mr. STEARNS. I would like to ask Mr. Dauchy if he has any data about the cost of hauling a cubic yard a mile, assuming that the material would be hauled to a distant dump?

Mr. DAUCHY. No; we have made no figures on that; we have made no estimates.

Mr. HUNTER. It would be a very trifling matter.

Mr. DAUCHY. Yes; the increased cost would be small.

Mr. WELCKER for Mr. GUÉRARD. Will it be possible to open quarries for obtaining stone at Bohio for the jetties to be constructed at Colon?

Mr. DAUCHY. It will be possible to open quarries at Bohio. I think it would.

Mr. WELCKER. It would be good stone?

Mr. DAUCHY. I think so. I should say so offhand. I have not looked into it. In my opinion it would be possible.

Mr. BURR. How many steam shovels are now set up and how many are waiting to be set up?

Mr. DAUCHY. When I left there last month, there were 11 set up and 6 others that were fairly well under way; probably they are completed at this time.

Mr. BURR. The total number on hand or ordered is 60?

Mr. DAUCHY. Yes. They are all Bucyrus machines, except possibly that last order. Mr. Stevens said he had given an order for the last lot, making 60 in all. I was talking with the purchasing agent yesterday. It is a question whether he had closed for the last 19; very likely they will close with the Bucyrus company. There was one order placed for locomotives—120 ordered for canal use.

The CHAIRMAN. One hundred and twenty locomotives?

Mr. DAUCHY. Yes, sir.

Mr. Dauchy was excused at 3.15 p. m.

DEPARTMENT OF ENGINEERING AND CONSTRUCTION, CULEBRA DIVISION,
Empire, June 1, 1905.

Statement of estimated force needed to prepare for and operate 29 steam shovels, 50 steam shovels, 81 steam shovels, and 100 steam shovels, also present force, balance needed, and portion of proposed force needed as each additional steam shovel is received between June 1 and December 31, 1905, December, 1906 (two estimates), and December, 1907, respectively.

Organization.	Monthly rate.	Total present force, 8 shovels.	Total force for 29 shovels, Dec. 31, 1905.	Total force for 50 shovels, Dec. 31, 1906.	Total force for 81 shovels, Dec. 31, 1906.	Total force for 100 shovels, Dec. 31, 1907.	Proportion of proposed force needed as additional shovels are installed.
Engineering and construction:							
Division engineer	$625.00	1	1	1	1	1	
Resident engineer	400.00	1	1	1	1	1	
Chief clerk	175.00	1	1	1	1	1	
File clerks	125.00	1	1	1	2	2	
Report clerks	125.00	2	2	2	2	2	
Routine clerks	125.00	0	1	2	2	2	Needed at once.
Stenographers	125.00	3	5	5	6	6	1 needed at once.
Clerks, II	100.00	1	1	2	2	3	
Technical studies:							
Resident engineers	250.00 to 300.00	[a] 2	2	3	4	4	
Assistant engineers	250.00	1	2	3	4	4	
Assistant engineers	225.00	[b] 2	2	3	4	4	
Instrumentmen	175.00	3	4	6	8	10	1 needed at once, balance proportionately.
Transitmen	150.00	3	6	8	10	12	3 needed at once, balance proportionately.

[a] At $275.

[b] At $200.

Organization.	Monthly rate.	Total present force, 8 shovels.	Total force for 29 shovels, Dec. 31, 1905.	Total force for 50 shovels, Dec. 31, 1906.	Total force for 81 shovels, Dec. 31, 1906.	Total force for 100 shovels, Dec. 31, 1907.	Proportion of proposed force needed as additional shovels are installed.
Technical studies—Continued.							
Levelmen, grade II	$125.00	5	6	8	10	12	1 needed at once, balance proportionately.
Levelmen, grade I	100.00	7	7	8	10	12	
Draftsmen, grade II	150.00	0	2	3	4	4	2 needed at once, balance proportionately.
Draftsmen, grade I	125.00	0	2	3	4	4	2 needed at once, balance proportionately.
Rodmen, grade II	83.33	6	8	12	14	18	2 needed at once, balance proportionately.
Rodmen, grade I	75.00	1	8	12	14	18	4 needed at once, balance proportionately.
Chainmen	60.00	6	6	8	10	12	4 needed at once, balance proportionately.
Machetemen (laborers)		85	250	350	500	500	165 needed at once.
Office—							
Clerk	125.00	0	0	1	1	1	
Clerk	100.00	0	0	1	1	1	
Stenographers	125.00	1	1	2	2	2	
Track maintenance:							
Superintendent	300.00	[a]1	1	1	1	1	
Assistant superintendents	250.00	0	2	2	2	2	1 needed at once.
Road masters	200.00	0	3	3	4	4	2 needed at once.
Supervisors	175.00	1	4	6	8	8	3 needed at once.
General foremen	150.00	11	11	18	24	30	1 with each new shovel installed.
Foremen, III	125.00	4	50	70	100	120	46 needed at once, balance proportionately.
Foremen, II	100.00	14	50	70	90	100	40 needed at once, balance proportionately.
Carpenter foremen	100.00	1	2	4	6	8	
Foremen	83.33	10	50	70	100	120	40 needed at once, balance proportionately.
Foremen	75.00	6	50	90	140	150	44 needed at once, balance proportionately.
Foremen	60.00	3	6	8	12	15	
Laborers		800	5,000	9,000	11,480	13,000	5,000 needed at once for preparatory work.
Office—							
Chief clerk	150.00	0	1	1	1	1	1 needed at once.[b]
Clerks	125.00	3	3	3	3	3	
Clerks	100.00	0	2	2	2	3	2 needed at once.[b]
Clerks	83.33	0	1	3	3	4	1 needed at once.[b]
Stenographers	125.00	0	1	1	1	2	1 needed at once.[b]
Transportation:							
Superintendent	300.00	0	1	1	1	1	1 needed at once.
Assistant superintendent	250.00	0	1	1	1	1	1 needed at once.
Trainmasters	200.00	3	4	6	8	8	1 needed at once, balance proportionately.
Supervisor road engines	200.00	1	1	1	1	1	
General yard masters	175.00	1	9	18	25	25	1 for every 3 shovels received.
Yard masters	125.00	6	15	25	40	50	1 for every 3 shovels received.
Yard masters	150.00	6	15	18	25	34	1 for every 3 shovels received.
Conductors	150.00	9	30	50	81	100	1 for each shovel received.
Conductors	125.00	18	30	50	81	100	1 for each shovel received.
Trainmen	100.00	25	30	50	81	100	1 for each shovel received.
Trainmen	83.33	12	30	50	81	100	1 for each shovel received.
Enginemen	150.00	16	60	100	160	175	2 for each shovel received.
Enginemen	125.00	31	60	100	160	175	2 for each shovel received.
Firemen	83.33	1	120	200	240	350	4 for each shovel received.
Laborers		135	135	250	350	400	4 for each shovel received.
Office—							
Chief clerk	150.00	0	1	1	1	1	Needed at once.[c]
Clerks	125.00	2	2	2	2	2	
Clerks	100.00	1	1	1	1	3	
Clerks	83.33	1	1	1	3	3	
Stenographers	125.00	1	1	2	2	3	
Messenger	25.00	0	1	1	1	1	
Mining:							
Superintendent	300.00	0	1	1	1	1	Needed at once.
Assistant superintendents	250.00	0	1	1	2	2	1 needed at once.
Supervisors	200.00	0	1	1	2	2	1 needed at once.
Supervisors	175.00	1	1	2	3	4	
General foremen	150.00	1	4	6	8	10	3 needed at once, balance proportionately.
Foremen steam and air	125.00	3	20	30	40	50	1 for every 2 shovels received.
Foremen drill workmen	100.00	11	20	30	40	50	1 for every 2 shovels received.

[a] At $250.

[b] Must have railroad experience in maintenance department.

[c] Must have railroad experience in transportation work.

Organization.	Monthly rate.	Total present force, 8 shovels.	Total force for 29 shovels, Dec. 31, 1905.	Total force for 50 shovels, Dec. 31, 1906.	Total force for 81 shovels, Dec. 31, 1906.	Total force for 100 shovels, Dec. 31, 1907.	Proportion of proposed force needed as additional shovels are installed.
Mining—Continued.							
Steam and air drill workmen.	$100.00	a 9	50	60	75	100	20 needed as soon as drilling tools received.
Helpers	83.33	6	50	60	75	100	20 needed as soon as drilling tools received.
Laborers		200	300	400	500	600	5 for every shovel till all received.
Office—							
Chief clerk	150.00	0	1	1	1	1	
Clerks	125.00	2	2	2	2	2	
Clerks	100.00	1	1	1	2	2	
Stenographers	125.00	0	1	1	2	3	1 needed at once.
Clerks	83.33	0	1	1	2	2	1 needed at once.
Assistant timekeepers	50.00	1	1	1	1	2	
Messengers	25.00	0	1	1	1	2	1 needed at once.
Excavation:							
Superintendent	300.00	0	1	1	1	1	1 needed at once, at $250.
Assistant superintendents	200.00	0	1	2	3	4	(Have one man now, rate $200, recently appointed in States, trying out.)
Supervisors	175.00	1	1	2	3	4	1 at once.
General foremen	150.00	0	6	10	15	20	1 for each 5 shovels.
Steam-shovel engineers	190.00	11	35	60	97	120	1 for each shovel.
Cranemen	165.00	10	35	60	97	120	1 for each shovel.
Steam-shovel firemen	83.33	a 4 b 11	35	60	97	120	1 for each shovel.
Pit foremen	83.33	a 7 b 4	35	60	97	120	1 for each shovel.
Foremen	100.00	2	2	4	6	8	
Foremen	125.00	1	1	2	3	4	
Assistant foremen	75.00	2	2	4	6	8	
Assistant foremen	50.00	1	1	2	3	4	
Office—							
Chief clerk	150.00	0	1	1	1	1	
Clerks	125.00	1	1	2	3	3	
Clerks	100.00	0	1	2	3	4	1 needed at once.
Clerks	83.33	1	1	2	3	4	
Stenographers	125.00	0	1	2	3	4	1 needed at once.
Messengers	25.00	1	1	1	2	2	
Dumps:							
Superintendent	300.00	0	1	1	1	1	Needed at once.
Assistant superintendents	250.00	0	1	2	3	4	1 at once.
Supervisors	200.00	0	2	3	4	5	1 at once.
Supervisors	175.00	3	3	6	8	10	
General foremen	150.00	1	8	15	20	25	1 for every 4 shovels.
Foremen	125.00	0	25	50	81	100	Need 8 at once, then 1 for each shovel.
Foremen	100.00	7	25	50	81	100	Need 1 for each shovel.
Foremen	83.33	0	25	50	81	100	Need 1 for each shovel.
Assistant foremen	75.00	2	25	50	81	100	Need 1 for each shovel.
Laborers		243	1,100	1,900	3,000	3,800	
Office—							
Chief clerk	150.00	0	1	1	1	1	Needed when superintendent is appointed.
Clerks	125.00	0	1	2	2	2	
Clerks	100.00	0	1	2	2	2	
Clerks	83.33	0	1	1	1	2	
Stenographers	125.00	0	1	1	2	2	
Messenger	25.00	0	1	1	1	1	
Maintenance of buildings:							
Camp supervisor	175.00	1	1	1	1	1	
General foremen	150.00	0	1	2	2	2	1 needed at once.
Carpenter foremen	125.00	2	2	4	6	6	2 needed at once.
Assistant carpenter foremen.	75.00	1	4	6	8	10	3 needed at once.
Carpenters		21	50	75	100	100	29 needed at once.
Foremen watchmen	83.33	1	1	2	3	4	
Roundsmen	75.00	0	3	6	8	10	3 needed at once.
Foremen	60.00	1	1	2	2	3	

a At $83.33. b At $75.00.

Organization.	Monthly rate.	Total present force, 8 shovels.	Total force for 29 shovels, Dec. 31, 1905.	Total force for 50 shovels, Dec. 31, 1906.	Total force for 81 shovels, Dec. 31, 1906.	Total force for 100 shovels, Dec. 31, 1907.	Proportion of proposed force needed as additional shovels are installed.
Maintenance of buildings—Con.							
Watchmen	$50.00	50	50	75	100	125	
Laborers		47	50	100	125	150	
Office—							
Chief Clerk	150.00	0	1	1	1	1	
Clerk	125.00	0	1	1	1	1	
Clerks	100.00	0	1	1	2	2	
Clerks	83.33	1	1	1	2	2	
Stenographers	125.00	2	2	2	2	2	
Messengers	25.00	0	1	1	1	2	
Water service:							
Superintendent	175.00	1	1	1	1	1	
General foremen	150.00	0	1	2	3	4	1 needed at once.
Pipe fitters	*a*.56	2	10	20	30	40	1 for each 2 shovels.
Laborers		29	100	125	150	200	10 at once, 3 for each additional shovel.
Office—							
Clerk	125.00	0	1	1	1	1	Needed at once.
Clerks	83.33	0	1	1	1	2	
Stenographer	125.00	1	1	1	1	1	
Mechanical maintenance:							
Division master mechanic	250.00	1	1	1	1	1	
Foreman of shops	175.00	1	1	1	1	1	
Roundhouse foremen	150.00	0	4	8	10	12	In proportion to shovels received.
Machinists	*a*.56	12	25	50	81	85	
Machinists' helpers	*a*.44	15	30	50	75	90	
Foremen (negro)	*a*.38	2	5	5	5	5	
Machinists (negro)	*a b*.50	23	30	50	75	90	
Boilermakers (negro)	*a b*.50	3	10	18	20	25	
Boilermakers' helpers (negro).	*a b*.32	1	5	10	15	20	
Blacksmith foremen	*a*.38	0	6	12	15	20	
Blacksmiths (negro)	*a b*.50	0	18	30	40	50	
Blacksmiths' helpers (negro).	*a b*.32	0	18	30	40	50	
Laborers		64	100	125	150	175	
Office—							
Chief clerk	150.00	0	1	1	1	1	
Clerk	125.00	1	1	1	1	1	
Clerks	100.00	2	2	2	2	2	
Clerks	83.33	0	1	2	3	4	
Stenographers	125.00	0	1	2	2	3	
Timekeeper	75.00	1	1	1	1	1	
Timekeepers	50.00	1	1	1	2	3	
Division quartermaster:							
Chief clerk	125.00	1	1	1	1	1	
Clerks	100.00	0	2	2	2	2	
Stenographers	125.00	1	1	2	2	2	
Timekeeping office:							
Chief clerk	150.00	1	1	1	1	1	
Clerks	125.00	1	1	2	2	2	
Clerks	100.00	7	7	9	12	14	
Clerks	83.33	5	5	7	10	12	
Time clerks	75.00	5	13	18	20	25	
Time clerks	50.00	7	14	18	20	20	
Stenographers	125.00	0	1	1	2	2	
Messengers	25.00	0	1	1	1	2	

a Per hour. *b* Silver.

All clerks and stenographers must be experienced in railroad service.

RECAPITULATION.

Forces now employed, and the forces which will be at work on the dates shown provided all the men needed to operate the number of steam shovels mentioned are furnished prior to these respective dates:

Certification.	Present force, 8 shovels	29 shovels Dec. 31, 1905.	50 shovels Dec. 31, 1906.	81 shovels Dec. 31, 1906.	100 shovels Dec. 31, 1907.
Division engineer	1	1	1	1	1
Resident engineer in charge of construction	1	1	1	1	1
Resident engineers	2	2	3	4	4
Assistant engineers, II	1	2	3	4	4
Assistant engineers, I	2	2	3	4	4
Instrumentmen	3	4	6	8	10
Transitmen	3	6	8	10	12
Levelmen, II	5	6	8	10	12
Levelmen, I	7	7	8	10	12
Draftsmen, II	0	2	3	4	4
Draftsmen, I	0	2	3	4	4
Rodmen, II	6	8	12	14	18
Rodmen, I	4	8	12	14	18
Chainmen	6	6	8	10	12
Superintendent of tracks	1	1	1	1	1
Superintendent transportation	0	1	1	1	1
Superintendent of mining	0	1	1	1	1
Superintendent of excavation	0	1	1	1	1
Superintendent of dumps	0	1	1	1	1
Superintendent of water service	1	1	1	1	1
Division master mechanic	1	1	1	1	1
Supervisor road engines	1	1	1	1	1
Assistant superintendent tracks	0	2	2	2	2
Assistant superintendent transportation	0	1	1	1	1
Assistant superintendent mining	0	1	1	2	2
Assistant superintendent excavation	[a]1	1	2	3	4
Assistant superintendent dumps	0	1	2	3	4
Train masters	3	4	6	8	10
General yard masters	1	9	18	25	25
Yard masters, I	6	15	25	40	50
Yard masters, II	6	15	18	25	34
Enginemen, II	16	60	100	160	200
Enginemen, I	31	60	100	160	200
Locomotive firemen	1	120	200	240	400
Conductors, II	9	30	50	81	100
Conductors, I	18	30	50	81	100
Trainmen, II	25	30	50	81	100
Trainmen, I	12	30	50	81	100
Road masters	0	3	3	4	4
Supervisors of tracks	1	4	6	8	8
General foremen, tracks	11	11	18	24	30
Foremen, III, tracks	4	50	70	75	80
Foremen, II, tracks	14	50	70	90	100
Foremen, I, tracks	10	50	70	100	120
Assistant foremen, III, tracks	6	50	90	140	150
Assistant foremen, II, tracks	3	6	8	12	15
Supervisors of mining	1	1	2	3	4
General foremen, mining	1	4	6	8	10
Foremen, III, mining	3	20	30	40	50
Steam and air drill men, mining	15	50	60	75	100
Miner foremen	10	20	30	40	50
Steam and air drill helpers, mining	1	50	60	75	100
Assistant foreman, mining	1	0	0	0	0
Supervisors, excavation	1	1	2	3	4
General foremen, excavation	0	6	10	15	20
Steam-shovel engineers, excavation	11	35	60	97	120
Steam-shovel cranemen, excavation	10	35	60	97	120
Steam-shovel firemen, excavation	15	35	60	97	120
Pit foremen, excavation	11	35	60	97	120
Foremen, III, excavation	1	1	2	3	4
Foremen, II, excavation	2	2	4	6	8
Assistant foremen, excavation	3	3	6	9	12
Supervisor, dumps	3	5	9	12	15
General foremen, dumps	1	8	15	20	25
Foremen, III	0	25	50	81	100
Foremen, II	7	25	50	81	100
Foremen, I	0	25	50	81	100
Assistant foremen, III	2	25	50	81	100
Camp supervisor	1	1	1	1	1
General camp foremen	0	1	2	2	2
Carpenter foremen	4	4	8	12	14
Assistant carpenter foremen	2	4	6	8	10
Carpenters	21	50	75	100	100
Roundsmen	0	3	6	8	10
Foremen watchmen	0	1	2	3	4
Assistant foremen, II	0	1	2	2	3
Watchmen	50	50	75	100	125
Shop foreman, general	1	1	1	1	1
Roundhouse foremen	0	4	8	10	12
Machinists	12	25	50	81	85
Machinists' helpers	15	30	50	75	90
Machinist foremen (negro)	2	5	5	5	5
Machinists (silver)	23	30	50	75	90
Boilermakers (silver)	3	10	18	20	25
Boilermakers' helpers (silver)	1	5	10	15	20
Blacksmith foremen (negro)	0	6	12	15	20
Blacksmith helpers (negro)	0	18	30	40	50
General foremen, water service	0	1	2	3	4
Pipefitters	2	10	20	30	40
Chief clerk, II	1	0	0	0	0
Chief clerks, I	1	6	6	6	6
Stenographers	8	17	22	28	33
Clerks, III	14	18	23	24	25
Clerks, II	12	19	25	33	35
Clerks, I	8	13	19	28	35
Timekeepers, $75	6	14	19	21	26
Timekeepers, $50	9	16	20	23	25
Messengers	2	3	4	5	5
Total	520	1,475	2,344	3,347	4,146
Laborers	1,670	7,335	12,800	17,165	19,925
Grand total	2,190	8,810	15,144	20,512	24,071

[a] This man recently appointed in States as "superintendent steam shovel crew," rate $200 per month. Request has been made to have title changed.

It is estimated there will be required to properly serve each steam shovel in operation 3 locomotives, 100 cars (French dumps), 2 unloaders, 2 bank spreaders, and 3 miles of tracks; therefore there will be needed—

	Engines.	Cars.	Unloaders.	Bank spreaders.	Miles of track.		Engines.	Cars.	Unloaders.	Bank spreaders.	Miles of track.
For 29 shovels, Dec. 31, 1905....	87	2,900	a 58	58	87	For 81 shovels, Dec. 31, 1906...	243	8,100	a 162	162	243
For 50 shovels, Dec. 31, 1906....	150	5,000	a 100	100	150	For 100 shovels, Dec. 31, 1907..	300	10,000	a 200	200	300

a Provided flat cars are used.

STATEMENT OF MR. JOHN F. WALLACE, OCTOBER 27, 1905.

The CHAIRMAN. I have the pleasure of introducing Mr. Wallace, whom you know personally or by reputation. Since Mr. Wallace's time in Washington on this occasion is limited, and as it will be more convenient for him to come before the Board some day next week than to submit to a long examination now, it has been suggested that there be placed in Mr. Wallace's hands the report of the remarks that have been previously made before this Board by Mr. Stevens, Mr. Maltby, Mr. Dose, and Mr. Dauchy, and that Mr. Wallace understand that it is the wish of the Board to question him concerning the canal project on the general lines of the questioning of the gentlemen named; that he take this data with him and at some day to be fixed that he be prepared to answer such general questions as were asked of the other gentlemen.

Is it the desire of the Board to-day to ask Mr. Wallace any particular questions in regard to the canal project? What is the desire of the Board?

Mr. HUNTER. Mr. Chairman, you might explain to Mr. Wallace what is so important a matter in the mind of every member of this Board. We would be glad to have the benefit of his experience and his advice as to what he considers to be the maximum quantity that could be removed from that central cut from Obispo to Paraiso in the course of twelve months after the proper appliances are installed; and, secondly, what length of time he contemplates would be required for the installation of a plant. Those are points of great importance.

The CHAIRMAN. In reading over the remarks that have been made and the questions that have been asked the gentlemen named, he will very quickly see that those are the points upon which much stress has been laid.

Mr. HUNTER. This is the point: What does he think the cost of removal would be of the material excavated from the divide?

The CHAIRMAN. Would it be convenient to you, Mr. Wallace, to take these data and study them and come back next week, say on Friday, prepared to answer as far as it is possible?

Mr. WALLACE. Yes, sir. Any knowledge or anything that I have is at your disposal, and if there is any assistance I can render it is at the disposal of this Board of Consulting Engineers. Of course, naturally I would like time for preparation, if possible, but I realize that your time is short. After I had answered your Chairman's letter I found I could cut a day out of my engagements this week. I did not know it until so late yesterday that I could not communicate with your Chairman. That is the reason I am here to-day. The study I made of the canal during a year's residence on the Isthmus went into a great many matters connected with the work of construction, and while I do not wish to even suggest presenting to this Board anything that I am not asked for, they might find it useful to have me present before the close of the ultimate conference a prepared paper giving my views of the various plans that I have considered and that may be suggested. This is entirely voluntary, but I would like to have that put into the record of the proceedings as part of my remarks. I can not give my views in a proper and logical way by simply answering questions that may be asked me by the members of this Board. In order that my remarks be of use and logical, they should be carefully prepared and presented. For that, of course, I would like more than a week following the information which you desire from me in answer to questions. I presume I could give you all of that, if the questions were in line with the questions that have been asked other gentlemen, by a week from to-day, provided those questions are not of a purely technical nature.

Of course you gentlemen understand that the men under me, from Mr. Dauchy down, saw the one detail that was assigned to them; that the scheme of operations, as it was formulated in

my mind or was in process of formulation as month after month went by and new difficulties came up and old difficulties were removed, was naturally a scheme that was never formulated in documents or in written form, and you will naturally realize that any one engineer having the burden of that work and its ultimate success upon his shoulders would be more concerned with the consideration of what he considered fundamentals, and in general the shaping up of his work along those lines, than in the purely technical solution of what he considered the minor details, which would naturally fall into their logical places during the after progress of the work and after the general plan had been finally decided upon. But in order to get at certain details, in order to get to certain conclusions in the consideration of larger, broader questions, it was necessary for me to do a great deal of detail work and to watch a great many detailed operations simply that they might be the basis of reaching a final conclusion later on. Now, naturally, if it would please this Board of Consulting Engineers, I would be perfectly willing, and I would desire, to present my final views in a regular, formulated way.

The CHAIRMAN. With maps and drawings?

Mr. WALLACE. I have no maps or drawings. I would not, in fact, propose to go into any detail whatever. I would propose to simply treat the subject in a broad, general way, dealing purely with fundamental principles and not with technical details. I do not know as it would be of any benefit to this Board, but there might be some advantages that would assist in the general consideration of the subject.

The CHAIRMAN. Would it contain any computation of quantities or estimate of cost?

Mr. WALLACE. Nothing except in a broad way. That is, for instance, it would be in order to state the preference of one plan over another, or, in order to demonstrate the question of time, to give quantities in round figures. As an example, comparing the element of time in the construction of two plans—say the sea-level plan and the 30-foot level or 60-foot level—the length of time that it would take for either one of the larger plans against the smaller one is not represented by the ratio or relation of the amounts to be excavated. The reason is that the use of time for preparation is common to all plans. A certain number of years is necessary in order that the progress of excavation reach the point beyond which further acceleration is impossible. In other words, during the excavation for a 90-foot or 60-foot or any high-level plan, the natural supposition is that the average rate of progress in yards to be removed per annum will reach the maximum ratio of efficiency, and that the time to do more work is not measured by the average amount which has been excavated during all the years, but the possible maintained maximum of yearly efficiency—of course qualified by the time that it would take to do the finishing work, as the progress of the work will naturally slow down toward the last. I simply give you that as an illustration of what I mean of dealing with quantities in the estimate of time.

It was impossible for me, and I presume it would be for any of you gentlemen, to be connected with that work in the capacity in which I was connected with it and not—to use the American expression—do a great deal of "mulling" over it, and, while it may be presumptuous to say so, I can not help thinking that you gentlemen should at least be entitled to know in a brief way what the result of those meditations were in regard to types of plans, etc.

The CHAIRMAN. It is quite obvious that the Board considers it desirable to know your views. That is proved by the fact that your presence was requested by the Board.

Mr. WALLACE. It is placed at your disposal cheerfully and at any time and to whatever extent of time may suit your convenience.

Now, after the first questions that you desire to ask, and until the investigations are completed and I file my brief with you, if you would still like to cross-examine me on the ideas which I may present, I am perfectly willing to come here a third time, if necessary. This statement will be short and condensed; I will try to boil it down so it will not consume any more of your time than is absolutely necessary to present the principal features; but I do not, in that, desire to take up any question of detailed technical studies, you understand, which you probably have already got a surplus of information on.

Mr. HUNTER. Mr. Chairman, perhaps you would explain to Mr. Wallace our difficulties here in respect of the limitation of time. Mr. Wallace has been good enough to accept a date; every day is of value, and while I am quite sure this Board will be unanimous in its anxiety to receive the brief that Mr. Wallace proposes to put on record, yet the value of that brief will very largely depend on the time it is given to us. Will you explain to Mr. Wallace the limitation of time?

The CHAIRMAN. The members of this Board who have come to us from Europe, and indeed all of the members of the Board, were told at the time of or shortly after their appointment that it was supposed by the Isthmian Canal Commission and by the Secretary of War that a period of, say, three months might be occupied by this Board in reaching a conclusion on the type of canal which should be constructed. In that statement, which was made to all the members, it was indicated that the month of September might be used for preliminary studies; the month of October for a visit to the Isthmus, and the month of November for working out final conclusions. Two months of that time have now elapsed, and the Board is now in the third stage of its work; has collected a great deal of information; is formulating its opinions; is developing the types, not only in respect to details, but the whole, and any contribution to effect results, as Mr. Hunter has very aptly stated, would have to be contributed at rather a close date; that is to say, a brief might come in after the Board had completed its studies, or nearly so, and there might be some points in it that were commendable, though the Board might feel that it was impossible to go all over its work and take up the study anew. That is what is meant about the limitation of time. Mr. Hunter has alluded to that limitation, and it is intended by this Board that we should finish our work in November, as the gentlemen from Europe expect to take passage for home at the end of that month, and therefore this brief to which you allude, in order to be useful, ought to be in the hands of the members of the Board at as early a date as possible, the earlier the better, and they would appreciate it very highly, no doubt, and would esteem it a favor if you prepared it at an early date.

Mr. WALLACE. If you will indicate, Mr. Chairman, the date which you desire to have that, I will furnish it, even if I have to cancel engagements to do so.

Mr. HUNTER. We want it badly this day a week.

Mr. WALLACE. All right; I will give it to you, with this understanding—that you will sympathize with the difficulties of a brother engineer in preparing so important a paper as that in such a short space of time.

Mr. HUNTER. We want you to sympathize with the difficulty of brother engineers, Mr. Wallace, who are now in the third month of absence from their work.

Mr. WALLACE. I will try to meet your wishes, Mr. Chairman.

The CHAIRMAN. The Secretary will hand you the remarks that have been made before the Board by Mr. Stevens, Mr. Maltby, Mr. Dose, and Mr. Bertoncini, although the latter mostly relates to drawings, etc.; also the statement of Mr. Dauchy.

Mr. WALLACE. Of course it goes without saying that all these questions with regard to hydraulics and river discharges and flow of water, etc., you will get from other sources.

Mr. HUNTER. I do not think Mr. Wallace need trouble himself about those things.

The CHAIRMAN. No; the physics and hydraulics are pretty well worked out in other reports. Then with that understanding we will excuse Mr. Wallace to-day and he will appear on Friday next at 10 o'clock.

Mr. WALLACE. Yes, sir.

Mr. STEARNS. There are a great many questions contained in the hearings of these different gentlemen, and possibly Mr. Wallace may be a little bewildered with the number of them.

The CHAIRMAN. He will see what is important.

Mr. WALLACE. I will take it for granted that you will not ask me any questions that have received satisfactory answers, and that you will confine the questions to those things that are important enough to warrant giving it my consideration.

Mr. HUNTER. We would like to have Mr. Wallace's opinion, whether formative or otherwise. There are a great number of details which these gentlemen discussed which it is not necessary to trouble him about. The point we are anxious about is time—the time which would be required

for the removal of certain quantities of material. He will see when he reads these papers that the Chairman named a quantity of 100,000,000 cubic yards at Culebra as a tentative basis, and that examination was made of these gentlemen as to what time would be required to remove that quantity and what it will cost; that is really what we want to know.

Mr. STEARNS. It seems to be a question of what it would cost and also as to the material in the great cuts. The great cut is a very important thing, particularly as to how it may be expected to stand. We saw that only for a day or two, while Mr. Wallace has stated he has "mulled" over it.

The CHAIRMAN. We asked a good many questions of these gentlemen which we would not think of asking you, and an inspection will show you what they are.

Mr. WALLACE. I can very readily put myself in the position of an individual member of this Board and imagine what I would like to know.

The CHAIRMAN. That is what we want. The Secretary will give Mr. Wallace that memorandum of General Hains on the cross section and estimate of costs which is here on the table.

Mr. Wallace was excused at 4 p. m.

NOTES ON THE PANAMA CANAL.

By John F. Wallace.

THE CHAGRES VALLEY, GAMBOA DAM SITE, AND RIVER CONTROL.

BORINGS AND ALIGNMENT.

The Panama Isthmus was evidently formed by the same upheaval that created the mountain ranges in the two American continents. The minimum disturbance and upheaval, however, occurred at the Isthmus of Panama. There the elevation of the original pass through Culebra was approximately 300 feet above the sea level. This pass, however, was so narrow that the slopes of the summit excavation have obliterated it; these slopes extending and cutting into the higher ground on the sides have made the excavation apparently much deeper.

The axis of the Isthmus extends in a general easterly and westerly direction, although trending slightly to the northeast and southwest in the general vicinity of the canal location at Panama.

Winding through the hills and coming down from a northeasterly direction parallel to the summit range to the southeastward, flows the Chagres, until it reaches Gamboa in the vicinity of Obispo, flanked to the northward by a secondary range in which, however, there is a decided break in the vicinity of Bohio.

Below Gamboa the Chagres takes an abrupt turn of over 90 degrees, and flowing to the northward enters the Caribbean Sea west of Colon and Limon Bay.

A careful study of the geology of the Isthmus has convinced the writer that at one time a narrow estuary of the sea extended as far inland as Obispo, and that the original mouth of the Chagres River was practically at the head of this estuary, above which point the Chagres possesses all the characteristics of a mountain stream.

In the dry seasons it is a limpid stream, a succession of deep pools of water clear as crystal, connected here and there with rapids where the river swiftly flows over gravel bars and through bowlders. While the hills below Gamboa on each side of the river between Obispo and Bohio approach to within a few thousand feet of each other, still the slope of the river is flat as compared with that above Gamboa. Below Bohio the valley gradually widens, and from Gatun the river courses through marsh lands to the sea.

Thorough investigations were made in the vicinity of Colon, which showed that there was no true rock in the harbor above the elevation of 50 feet below the sea level.

The harbor itself is filled with soft material to a great depth, except the coral reef upon which the outer edge of Colon is located, extending up to and slightly beyond the mouth of the canal as located by the French engineers in the vicinity of Cristobal Colon. This coral ledge is only 9 to 12 feet in thickness and underlaid by clays and alluvial deposits.

At different points along the line of the canal, various seeming rock formations were encountered, but all were of a sedimentary nature, generally clay formations which could be easily cut with a "machete," never more than hard compact clays of very fine grain. Above the surface of the water in some places it had the appearance of wave-washed rock.

In some localities a rock of the pudding stone or a conglomerate nature was found, composed of gravel, bowlders, and sediment cemented together; but what was ordinarily known as bed rock was not found to exist near the surface at any point along the Chagres Valley between Obispo and Colon.

As the topography of the country was not suitable for dam sites between Gatun and Colon, it was not necessary to take borings for a distance of more than 50 feet below the level of the sea, as 40 feet below the sea level would be the maximum depth of excavation.

As a possibility for a dam site had been suggested in the vicinity of Gatun, thorough diamond-drill borings were made in this locality, the result of which showed that no continuous bed rock existed above the elevation of 200 feet below the sea level. This does not mean, however, that the lowest point of the bed rock in this vicinity existed at 200 feet below the sea level, or that it did not exist at much greater depths at other than those points where borings were taken; but as 200 feet was considered in excess of the practicable depth at which it was advisable to construct a foundation for a dam, it was not considered necessary to go deeper.

Owing to the fact that the report of the first Walker Commission was based upon the construction of a dam at Bohio, extraordinary care was taken in the investigations made at that point, and not only were the borings taken with a diamond drill, but when what was supposed to be bed rock was encountered, cores were taken from the rock, in some cases to the depth of 25 or 30 feet, in order to determine the nature of the material and the fact that it was the bed rock beyond doubt. Borings were also taken at intervals as close as 50 feet apart on various lines in order that the maximum depth of the original geologic gorge might be thoroughly ascertained. At this place the lowest point of bed rock was definitely determined at approximately 167 feet.

The original gorge was found to be filled with a heterogeneous mass of material. While immediately next to the bed rock there existed a shallow stratification of clay, above was a loose porous deposit of bowlders and coarse gravel interspersed with masses of driftwood and the various forms of detritus usually brought down into an alluvial valley by a mountain stream.

The careful tests made showed the material to be freely water-bearing, and more so as the bed rock was approached, the water being fresh even at the maximum depths.

All of the favorable points in the valley between Bohio and San Pablo were carefully explored, and while the bed rock showed a tendency to rise farther up the river, it was not found at such depths as to warrant the selection of a dam site which would be any more favorable than that at Bohio, considering all of the circumstances connected with the situation.

The borings taken at Gamboa, however, across the valley of the Chagres to the eastward of Obispo, developed the bed rock to be at sea level, and the conformation of the topography above the surface at this point rendered it, together with the higher elevation of the bed rock, an ideal situation for the location of a dam.

The general results of the surveys and examinations between Obispo and Colon tended to the conclusion that bed rock existed at some unknown depth greater than 200 feet between Bohio and Buena Vista, gradually rising toward the latter point; and also that the sea evidently originally occupied this valley as far as Obispo, which point at some time was the mouth of the Chagres River.

During the ages that have since elapsed, the heavy rains of the tropics feeding the Chagres and the floods of the river have been gradually filling up this estuary with the débris washed down from the high lands.

Bowlders, gravel, and heavier sands were first deposited in the upper part of the original gorge until it had been partly filled and a new slope established, allowing such a slackening of the current as to permit of a deposit of clays, interspersed with beds of gravel and sand, dependent upon the height and nature of the various floods that occurred.

When these waters spread out, however, on the flatter slopes of the lower Chagres, and the current became deadened by its contact with the sea, the finer clays were deposited. It is also probable that a gradual subsidence has occurred, and that that part of the Chagres Valley which is now below sea level was at one time at a higher elevation.

Mr. Ehle's surveys of the upper Chagres Valley developed the possibility of securing a much larger flood-lake area by the construction of the Gamboa dam than was indicated by the original topographic maps, and his investigations also determined the length and possibilities of a tunnel route for diverting the surplus waters of the Chagres contained in the Gamboa dam into the headwaters of the Juan Diaz, on the Pacific slope; and, further, an alternate plan for the diversion of these waters on the Caribbean slope.

On the latter, which was a shorter and less expensive line, a plan of an open cut was evolved, and also such data of a hydraulic nature were obtained as would enable a proper determination to be made of the control of the Chagres River through the construction of the Gamboa dam and works of an incidental nature. Briefly, Mr. Ehle determined the following facts:

The practicability of the construction of a dam at Gamboa, which, constructed at certain elevations, would give surface areas as shown below:

200 feet above sea level, a lake area of approximafely 43 square miles.
170 feet above sea level, a lake area of approximately 31 square miles.
132 feet above sea level, a lake area of approximately 15 square miles.

These areas were determined by the estimates based on actual surveys, the bed of the Chagres River being at approximately 50 feet above the sea level at Gamboa. The 200-foot contour line was determined by actually running a line at that elevation around the sides of the valley.

Without going into details of the hydraulic problem it is sufficient to state that the results of investigations determined the practicability of a dam at Gamboa creating a lake of sufficient dimensions to control the flood waters of the Chagres River, and also gave the data for determining the question of the control of the average flood of the Chagres as regulated by the lake created by the construction of this dam, and indicating several methods by which this result could be accomplished, the estimated cost thereof being contained in the official reports, with full details.

From the data obtained the writer can see no reason why it would not be practicable to permit the waters of the Chagres River as controlled by the Gamboa dam project to enter and follow the regular canal prism, which would give two outlets to the sea, one in each direction, as the average discharge of the Chagres River through the entire year could be easily taken care of in the canal prism without materially interfering with either the maintenance or operation of the canal, although it might be well to prepare for taking care of a portion of this water through a parallel conduit, which would also intercept the drainage of the hills on the east side of the canal and act as a diversion channel.

Especial attention is called to the Gamboa dam location for the reason that it is a necessary adjunct to any plan of a canal which may be decided upon at sea level, or the summit level of which may be at any height not exceeding 60 feet, and in which an intermediate navigable lake would not be a necessary feature.

While further detail work should be carried on by the parties in the field to more fully settle questions of minor detail, the essential and basic facts have been secured from the investigations sufficient to enable proper consideration to be given to the general plan.

TECHNICAL STUDIES.

After the essential facts in relation to the subformation of the Chagres Valley had been obtained, the diamond-drill parties were assigned to the work of systematic borings along the central line of the canal axis, in order to determine the character of the formation to an elevation of 50 feet below the level of the sea, the first borings being taken about a kilometer apart, these being followed by intermediate borings, which, it was planned, were to continue until the formation was thoroughly explored along and adjacent to the axis of the canal, supplementing and perfecting the system of borings which had been carried on by the French engineers with the same purpose in view.

The results thus far obtained indicate great irregularity in the geologic formation of the Isthmus. For a few hundred feet in the Culebra cut basaltic rock exists. The surface of this rock, however, descends rapidly toward the Pacific and is not continuously found above the line of 40 feet below the sea level. Northward of the dividing ridge at Culebra the stratification gradually changes to slate, and later to shales and clays, while near Obispo considerable of the pudding stone and conglomerate formation is encountered.

Practically no regular stratification exists. Occasionally perpendicular ledges of hard rock a few feet in thickness forming dikes exist at right angles extending across the canal axis. While occasional trap and also limestone and sandstone formations were found at irregular

intervals, there is no continuous regular rock formation above a line of 40 feet below the sea level northward of Culebra; slate formations, shales, clays, sand, and gravel forming the greater mass of the material.

During the progress of the surveys in the Chagres Valley, a party of topographic engineers under the direction of Mr. Ruggles was at work exploring and carefully mapping the topography of the country between Obispo and Pedro Miguel, covering the section of the canal from the point where it left the valley of the Chagres through the continental divide and entered the low lands of the sea-level section in the valley of the Rio Grande on the Pacific slope.

The object of Mr. Ruggles's surveys and investigations was to determine whether or not the French location could be improved upon, and also to ascertain the quantities of material to be excavated in accordance with all of the various plans under consideration.

The investigations of Mr. Ruggles determined the advisability of adhering to the location of the central axis of the canal as adopted by the French.

During the year the various hydraulic and meteorologic observations which had been taken under the French administration were continued, and the compilation and analysis of these results was assigned to Mr. Arango, member of the American Society of Civil Engineers, who had charge and was at the head of the bureau controlling this part of the work.

CULEBRA EXCAVATING WORK AND COST RECORDS.

As the work of excavation under way by the French could be carried forward without interference with any future plan of work which might be decided upon, it seemed highly important to continue it and demonstrate by actual work the elements of cost and the efficiency of the various appliances and methods along the following lines to the end—

First. That the methods used be such as would enable the maximum number of excavating units of maximum capacity per unit to be employed.

Second. That in selecting the various appliances the measure of utility should be the quantity of output and cost per unit.

Third. That no appliances or methods be used that actual experience had not shown to be efficient.

When a thoroughly competent, able, and efficient organization is at work on the Panama Canal, and the work is going forward at the maximum rate of progress possible under all the circumstances surrounding the situation, the larger part of the work will have been accomplished, and the results of the first or second year's work can not be fairly measured by the yardage of material removed.

This work was carried on during the year, and expanded to such an extent as the many difficulties in the way of securing men and material would permit.

The result of the experimental work between May 4, 1904, to January 1, 1905—eight months—was the excavation of 243,472 cubic yards of material, an average of approximately 30,000 cubic yards per month. at an average cost of 55 cents per cubic yard, the output varying from 27,000 cubic yards in May to 43,000 cubic yards in December; maximum cost per cubic yard being 68.6 cents, in May, and the minimum cost being 50 cents per cubic yard, in December. The elements which entered into such costs were those which would necessarily be assumed by any contractor doing the work, and not including the administrative or engineering expense which would be necessary, whether the work was carried on by contract or hired labor under direction of governmental supervision.

During the next three months, ending March 31, 1905—the dry season—278,680 cubic yards were excavated, at an average cost of 45 cents per cubic yard, the maximum output being 133,000 cubic yards, in March, at a minimum cost of 43 cents per cubic yard; these figures, however, include an arbitrary of 6 cents per cubic yard to cover the average cost of new plant sufficient to absorb the entire cost of new plant and equipment needed in the work, and also the rebuilding of such of the old French plant as could be utilized.

The result of the three months' work of April, May, and June, 1905, however, shows the amount excavated to be 279,589 cubic yards, at an average cost of 75 cents per cubic yard. In

order to analyze the result for the last three months it is necessary to consider each by itself. In April the output was 126,750 cubic yards, at an average cost of 52.5 cents, the rainfall during this period being 3 inches. In May the output decreased to 76,000 cubic yards, and the cost increased to 84 cents, the rainfall being 13 inches, an increase of 10 inches. In June the output was 77,000 cubic yards, cost $1.03 per cubic yard, and the rainfall was 7 inches.

The increase in cost in May, and more particularly in June, was due to the combination of many causes culminating in June—the establishment of the eight-hour day and general increase in compensation; the unbalanced condition of the forces due to the difficulty of obtaining men promptly in the proportion needed for the different parts of the work; the necessity of providing men for future requirements aggravated by the constant leaving of employees discouraged with existing conditions, but more particularly due to the fact that labor and material were not furnished in sufficient quantities to carry out the preparatory work necessary to be performed during the dry season—December to April—in order that the work might be economically and efficiently conducted and carried forward during the wet months of the balance of the year.

This, of course, was aggravated by the fact that the French engines, cars, tracks, and appliances were not satisfactory for the efficient conduct of the work. The long and rigid wheel base of the French and Belgian engines in combination with the short track rail of high section, together with the necessity of operating over poorly ballasted tracks, caused an extremely large number of derailments, preventing the proper supply of empty cars to the various steam shovels and their removal when loaded; consequently the steam shovels were operated at one-half of their practical ordinary capacity, and less than one-fourth of their theoretical efficiency.

With proper auxiliary machinery and appliances, and with sufficient suitable track facilities in connection with the American steam shovels, the amount of output would only have been limited by the number of steam shovels at work multiplied by their full practical capacity, which would naturally have resulted in a largely increased output and a reduction in the cost, even as compared with the result obtained during January, February, March, and April.

It is not to be expected that more favorable results will be obtained either in quantity or cost until the next dry season, as compared with the results of the three months ending June 30, 1905, unless the expansion and building up of the construction departments be discontinued and the work carried forward on a small scale, retaining the more experienced men and only working those steam shovels which are served by track systems in the best condition, using such of the engine and car equipment as is best adapted to the work.

However, the cost per cubic yard during the next few months is mainly important to determining the experimental value of the various elements affecting the work. It may be interesting to note here that the total output for the fiscal year ending June 30, 1905, was 741,644 cubic yards, at an average cost of 58.6 cents.

Overconservatism on the part of the writer may have induced him to overestimate the value of results obtained from actual practice, but it was considered that if a record of the cost of every function of the work was properly recorded and tabulated, the data obtained therefrom would be valuable in making estimates for the consideration of general plans and in the determination of various questions which would arise during the progress of the work, as to the relative efficiency of the machinery, appliances, organization, methods, and men.

The system of daily and monthly cost sheets, with explanatory reports, put into effect by the writer, were such as to give the fullest possible information as to the efficiency and progress of the work.

The cost of each function and all the details subordinate thereto were tabulated. Comparative costs of operation of each excavator and steam shovel were shown separately. Also the cost of excavation and removal of various classes of material; cost of operating different dumps; of operating over each separate system of tracks, and the different distances; cost of work performed by different groups of men—all based on the unit cost per cubic yard.

In the transportation work the cubic yard moved 1 mile, practically equivalent of the ton-mile, was the unit considered.

SEA-LEVEL SECTIONS OF CANAL.

Under the direction of Division Engineer Maltby, in whose charge was given the sea-level sections of the canal and the harbors at Colon and La Boca, French dredging plants were overhauled and put into commission to enable such dredging to be done as would permit access to be maintained to the wharves at La Boca on the Pacific end and Cristobal Colon on the Caribbean end of the canal.

These two plants developed a working capacity each of approximately 2,500 cubic yards per day, at a cost of less than 10 cents per cubic yard.

Plans were made for increased wharf facilities at both Cristobal Colon and La Boca, the execution of which, however, was delayed by the nonreceipt of proper material.

Time and space will not permit of a detail description of the large amount of preparatory work carried on under the various bureaus and subdepartments, particularly in the mechanical and machinery department, overhauling of the French machinery, the planning and arranging for the construction of new shops, and the installation of machinery for the rebuilding of French engines, cars, and other equipment, and the general work of maintaining and repairing plant during the future progress of the work.

COST OF CULEBRA WORK FROM JULY 1, 1904, TO OCTOBER 1, 1905.

[In reply to statement of October 14, 1905, submitted to Gen. George W. Davis, Chairman of the Board of Consulting Engineers, by Mr. John F. Stevens.]

While the writer of these notes was appointed chief engineer of the Isthmian Canal Commission effective June 1, 1904, conferences with the Commission at Washington and the time consumed on the voyage to Colon prevented him from assuming actual charge of the work on the Isthmus until July 1, 1904. During the latter part of September and October he was called to Washington by the Commission and, returning to the Isthmus, was again in active charge of the work during the months of November, December, January, February, and March. In the latter part of March, 1905, he was ordered to Washington on account of the reorganization of the Commission, and was detained in the States until the latter part of May. He again left the Isthmus on June 16 for further conference with the Secretary of War, and terminated his connection with the service on June 29, 1905.

Therefore he can give no explanation of the extraordinary increase in the unit cost of the work during August and September, 1905, except so far as an analysis of the statement submitted can furnish its own internal evidence of an explanation. The diminished output in August and September would seem to furnish the explanation in part, either indicating a change in supervision and conduct of the work, or of accounting. Therefore the analysis of this statement by the writer will be confined to the twelve months ending June 30, 1905.

On assuming charge of the work the writer found that practically all work was being done by hand and very little attempt was made to use even such French machinery as was available, and his efforts during July, 1904, were directed toward observation of the methods of work and arranging for the installation of such French machinery as could be utilized, which resulted in an immediate diminution of the unit cost. The falling off in the quantity excavated during September and October, and the increase in the unit prices, was due to the excessive rainfall during those months. The record of the rainfall for the year at Culebra will be noted on the attached sheet (see p. 359).

After the writer's return to the Isthmus, in November, the force was gradually increased, and during the month the first American steam shovel was installed, which was followed by others in December and later.

From December to February, during the four months of the dry season, the output gradually increased and, as noted, the unit cost correspondingly diminished. Commencing with April, however, the output again declined and the unit cost rose. In spite, however, of the excessive rainfall in May and the culminating effects of the rain in June the output for the months of May, June, and July was practically the same.

The increase in the unit cost for May and June and July was due to a variety of causes. First, the decision of the Attorney-General requiring the installation of the eight-hour day practically increased the cost of the work 20 per cent, as it was decided that the law should be enforced according to its spirit, which required that the labor be paid the same for eight hours as previously for ten. This course was also necessary in order to retain the labor. The larger part of the increase, however, was due to the fact that the scarcity of material and labor prevented the preparatory track work and other work being done during the dry season in order to maintain the rate of progress and increase it by the installation of additional steam shovels, as had been planned by the chief engineer; the rails, engines, car equipment, drilling machinery, and, in fact, the entire plant with the exception of the modern steam shovels installed being unsuited to the vigorous and economical prosecution of the work.

MINING.

Analyzing the various items it will be noted that the cost of mining showed a gradual reduction for November to April, inclusive, the increase in this item for May and June being due to an increase in the wages and the application of the eight-hour day. While slightly affected by rainfall, this did not materially increase the cost, the increase due to this cause alone being insignificant.

There is no reason why, with the introduction of compressed-air drills and proper supervision, the average cost of mining on the entire work should exceed 12 cents per cubic yard.

EXCAVATION.

Examining the cost of excavation, it will be seen that it was fairly reasonable and practically uniform from October to April, inclusive, the increase in May and June being due to the increased rainfall and the application of the eight-hour day.

While the rainfall did not interfere with the operation of the shovels themselves, it prevented the necessary track work, the unloading of cars, and interfered with the transportation element of the service in such a way as to materially retard the prompt supply of equipment to the shovels and the removal of loaded cars.

It may be stated here that even the costs as shown on this sheet between October and April would never have been over 3 or 4 cents could empty cars have been promptly supplied to the shovels and loaded ones promptly removed, as at no time have the shovels performed over 25 per cent of their capacity for the actual hours employed; and in the opinion of the writer it is easily within the range of reasonable practicable possibility for these shovels to average 1,000 yards per working day, even when operated in large numbers, provided ample and proper facilities in the way of tracks and transportation are furnished.

As train men can be paid by the month and are not supposed to come under the restrictions of the eight-hour day, a large part of the work which was formerly done inside of the ten hours could now be performed outside of the eight-hour day, enabling the shovels to work more continuously and practically accomplish in eight hours what they formerly did in ten hours. In other words, it is possible by proper management to overcome the loss due to the adoption of the eight-hour day as far as the ability to handle the material by the excavating units is concerned.

The writer would consider 7 cents per cubic yard as an outside average price to cover the operation of excavating and loading material with steam shovels.

MAINTENANCE OF TRACKS.

This item is dependent largely upon the tracks being put in proper condition during the dry season, so far as the main and principal tracks are concerned, and during the wet season on the efficiency of the track force and its proper supervision.

It should be remembered that the work performed during the first year on the tracks was done by unskilled labor and under the immediate supervision of ignorant and practically unskilled foremen. From the writer's experience in track maintenance in the United States, particularly in Mississippi and Louisiana, where the work is performed under conditions approximating those

of the Isthmus, he sees no reason why the cost per cubic yard of track maintenance should not steadily decrease as the work progresses until the output has reached its maximum, and he considers that 5 cents per cubic yard throughout the entire progress of the work would be an ample allowance to make for this item.

TRANSPORTATION.

The average for the five months, October to March, inclusive, was approximately 10 cents per cubic yard. The increase in cost from that time forward was due to a variety of causes. First, as the men in this department were more easily obtained from the United States than other classes of employees a number were sent to the Isthmus out of proportion to the necessities of the work, and, as it was to be presumed that the requirements of the work would increase and the ability of the various men could only be determined by actual trial, this force was kept larger than would afterwards appear in a properly balanced organization. Again, it must be remembered that the derailments which from the 1st of April to the 1st of July occurred in large numbers immediately affected the expenses in this department. This was due to poor tracks, but more particularly to the long rigid wheel base and inflexibility of the rolling stock. The French and Belgian engines were constructed of the best material and of the finest workmanship, but so closely fitted as not to give the flexibility in moving which is desirable in engines used in constructive work over rough and irregular tracks. This was also aggravated by the fact that the rail used was of the most unsuitable section—narrow base, high, and short. The shorter the rail, the stiffer and more inflexible it is and the harder to obtain suitable tracks, particularly temporary ones for construction purposes.

The result of this combination of causes was continued derailments, which not only affected the cost of transportation in a very large degree, but also increased the cost of track maintenance and the cost of excavation, on account of the irregularity in the car supply at the steam shovels.

The experience of the writer would lead him to believe that with proper equipment and proper tracks the cost of transportation should average less than 10 cents per cubic yard throughout the entire conduct of the work, after proper facilities have been provided.

DUMPS.

It will be noted that for the first ten months of the year, up to and including April, the average cost of dumps did not exceed 5 cents per cubic yard. The conditions which finally brought the average cost up to 6.59 cents for the entire year occurred after the 1st of May.

The system of dumps was the same as used by the French company, as the lack of proper material, labor, machinery, and appliances prevented the execution of the general plan of transportation and dumping arrangements which the chief engineer had under consideration.

The expense charged to dumps was that incurred after the delivery of the cars to the dump track by the transportation department and subsequent to the removal of the empties, including the unloading and spreading and the shifting of the dump tracks in order to provide for the unloading.

With proper facilities and appliances there is no reason why, in the opinion of the writer, the cost of dumps should average in excess of 5 cents per cubic yard for the entire work.

GENERAL EXPENSES.

In the general expense should be carried all items of cost which are not included under the other specific headings. All charges for new machinery, new tracks, new appliances, or new quarters for the men should be and were included in the arbitraries. All charges for fuel, repairs of machinery, cars, equipment, or tracks should be and were distributed under the general headings into which the costs of work are subdivided, the general expense containing all other charges and only such as could not be properly and suitably distributed under subordinate heads.

The unit cost per cubic yard of the general expense will naturally diminish as the volume of the work increases, as it will not increase in the same ratio as the output, and with the work

under full headway the average per cubic yard should be reduced to a small amount on the cost per cubic yard of the output.

In the writer's opinion, throughout the conduct of the work this expense should not exceed 3 cents per cubic yard.

It is again called to the attention of the Board that the costs contained in this statement were obtained by experimental work under the most disadvantageous circumstances, with crude machinery and an ill-assorted force of inexperienced men, but that an endeavor was made to handle the classes of material in approximately the assumed proportion which would exist throughout the work, and that the probable unit prices suggested were arrived at not only after a careful study of actual conditions on the ground during a year's experience, but also in view of the writer's experience in other work of a similar nature carried on under his supervision in the United States, and also considering the economies which can be effected by the installation and adoption of proper machinery, appliances, methods, and supervision.

The total of the various units suggested by the writer aggregates 48 cents per cubic yard, including arbitraries. While he feels that efficient supervision, such as a contractor would give to this work, might very materially reduce some of the items of cost enumerated herein, he suggests in the consideration of the question that 50 cents per cubic yard, in round figures, would be an ample unit cost for the entire work, which, however, for greater safety, might be increased 20 per cent, which would be considered the profits of a contractor during the work, bringing the estimated cost up to 60 cents per cubic yard.

With reference to the distribution or figuring items of cost, while the suggestion might be made that theoretically mining should be considered part of the excavating and transportation part of the dumping branches, it should be borne in mind that this distribution of costs, devised and instituted by the writer, was intended to so subdivide the work as to enable the chief engineer to properly measure the efficiency of men and appliances. For instance, the superintendent in charge of mining and the men under him should be measured by the cost of mining alone. In the excavating and loading department, the efficiency of the superintendent of steam shovels and the men operating them would naturally be measured by the cost per cubic yard of the actual steam-shovel work, as account can be kept of each steam shovel separately and the measure of efficiency ultimately applied to each individual excavating machine.

In the maintenance of tracks, the various supervisors and foremen in charge of different sections of track work can be measured by the number of miles of track each had to maintain, but as it is affected by the tonnage passing over the same, the cost per cubic yard, which is the measure of use made of the tracks, should be considered.

Under the head of transportation is all the expense that is due to the moving of cars from the time the loaded car is taken from the shovels until the empty car is returned thereto; and the cost per cubic yard moved some distance, say 1 mile, will naturally be the measure of efficiency applied to employees of this department. This record can be kept for each train crew or each set of crews, and again each division of the work can be segregated and its efficiency measured thereby.

On the dumps, where a foreman with a gang of men is stationed, whose function it is to render such assistance as may be necessary in addition to train-crew work, unloading cars and maintaining tracks actually on the dumps and spreading the material, the cost per cubic yard of the material dumped is, with proper consideration being given to other conditions, a fair measure of the efficiency.

This unit of efficiency can also be applied in comparing the cost of various dumps and determining whether it is more economical to form a high dump with only occasional movement of tracks but with excessive bank settlement, or to spread the material for a low dump over a larger area with more frequent movement of tracks.

While it is doubtless true that the cost of one part of the work is affected by others with which coordinate work is carried along, still the writer has found in his experience that a careful record of cost units, changing and modifying the system as necessary from time to time, with proper analysis, not only gives the person in responsible charge of the entire work a knowledge and control which he could not possibly obtain from simply general observation, although close

and general observation is necessary to intelligently apply it, but also impresses every superintendent, supervisor, foreman, and individual workman that his efforts are properly and intelligently watched by the highest authority on the work, and that the records will approximately show his relative efficiency. The effect of and inspiration caused by methods of this character should largely increase the economical and efficient conduct of the work.

The writer has dwelt on this subject rather at length, as, while these conclusions may not be strictly accurate, he considers that the experimental results of a year's work, modified by his knowledge of what can be done with improved machinery and appliances and proper methods, would at least be a guide in arriving at some approximate idea of the cost and time required to complete excavation work on the principal plans under consideration.

ARBITRARIES.

What are called arbitraries for the plant and appliances were intended to absorb the entire cost of the plant during the work, and it was thought more fair to add an arbitrary each month to the cost price per cubic yard than it was to add the cost of new plant or installation work into each month's costs, the idea being that the comparative cost per cubic yard each month should only include those items that affected the month's work, as new tracks, new equipment, new appliances, or other extensive installations would be in the way of benefit to the entire work, and it was considered fair to average them in in the form of arbitraries which could be increased or diminished or otherwise modified as experience should show to be proper.

It is considered, however, that the amount provided, 6 cents, will be sufficient to cover the cost of this class of expenditures. In these cost sheets it was intended to include all the charges to which a contractor should be subjected. A large portion of the general expense, supervision, engineering, sanitation, etc., would be common to any method of carrying on the work, and would be provided for by the Commission even if the work was let by contract, except in case the entire work should be let to a syndicate and the Government relieved of a portion of the expenses of this nature. As in the original estimates a percentage has always been added to cover general expenses, supervision, engineering, and sanitation, the figures of cost have been confined to the lines indicated.

As will be noted, the elements which go to make up the total unit cost per cubic yard are as follows, and the 2 cents added to the cost of 48 cents may be made available for additional equipment if the arbitraries allowed are not sufficient for the purpose:

Mining	$0.12
Excavating and loading	.07
Maintenance of tracks	.05
Transportation	.10
Dumps	.05
General expenses	.03
Arbitraries	.06
Total	.48
In round numbers	.50
Adding 20 per cent for contingencies	.10
Total estimated cost per cubic yard	.60

Statement of rainfall at Culebra from July 1, 1904, to June 30, 1905.

1904.	Inches.	1905.	Inches.
July	[a]6.5	January	1.9
August	3.5	February	0.0
September	13.6	March	1.2
October	10.8	April	2.9
November	12.8	May	13.1
December	1.8	June	6.9
		Total	75.0

[a] Estimated.

VARIOUS SUGGESTED PLANS.

The principal problem is the removal and disposal of a determined amount of material by modern appliances and methods, under efficient management and organization, and conducted on business principles.

The low-level, intermediate-lake plan suggested by Mr. Bates only saves a small amount of work due to the last 20 or 30 feet of excavation. In lieu thereof, however, there is substituted a large amount of dam and dike construction resting largely on alluvial formations, and expensive breakwaters exposed to the open sea.

The plan suggested by the first Walker Commission is objectionable, first, on account of the fact that it would be impracticable to provide a sea-level canal in the future; second, that the principal feature in this plan (the Bohio dam) would have to be constructed at a point where the bed rock is at a depth of 167 feet below sea level, overlaid with material of a freely water-bearing nature, and which, while not impractical of construction, involves the use of experimental methods, the cost and result of which are undetermined quantities.

While it might be wise to consider this plan if the accomplishment of the result depends thereon, its adoption would hardly seem justifiable in comparison with others under consideration.

The various high-level, multilock plans are objectionable for the reason that they render the construction of a future sea-level canal impracticable, except by the expenditure of a larger amount than present or possible future conditions would seem to warrant, although the plan of Mr. Bunau-Varilla for deepening and enlarging the canal is certainly entitled to consideration and is ingeniously devised.

It is possible that some modification of this plan might be practical in connection with a lock canal of comparatively low elevation, in case Congress should decide that it did not care to commit itself at the present time to a sea-level canal on account of its cost and the time necessary to construct, and on the other hand does not wish to adopt any plan which would make the sea-level feature impossible in the future.

The writer in his study of this question has been more or less controlled by what he considered certain fundamentals:

First. That no high dam should be constructed that could not be founded on bed rock or to which an impervious curtain wall could not be carried.

Second. That the construction of any high dam should be avoided the destruction of which would prevent the operation of the canal until the dam had been replaced.

Third. That if it became absolutely necessary to construct dams on alluvial foundations, the plan should be selected necessitating the smallest amount of construction of this character, and subject to the least possible head of water retained thereby.

In considering the statement which has been oft repeated of the advantages of intermediate lake navigation, it should be borne in mind that even with the idea carried out to its fullest extent there will yet remain 10 miles of ordinary canal section through the continental divide. It should be remembered that the 10 miles on the Pacific slope west of Pedro Miguel can be easily made to any width by dredging without going to any extraordinary expense, and that the 12 miles from Matachin to Bohio, on the Caribbean side, will not involve an excavation in excess of 100 feet depth, even for a sea-level canal, with the possible exception of one or two points a few hundred feet in length.

The 15 miles from Bohio to the Caribbean Sea is composed entirely of alluvial or sedimentary deposits, and while some of the latter approach the character of soft rock, there is nothing that can not be handled by ordinary submarine methods. Additional width of section can be obtained without extraordinary expense except through the Culebra section, which is common to all plans.

The mere comparison of the quantities of material to be excavated should not be used as a measurement of the difference in time and cost necessary to complete a sea-level or low-level as against a high-level canal.

First, the time required for sanitation, organization, and preparation would remain practically the same with any plan that might be adopted. It is also self-evident that the maximum

rate of output after actual construction is commenced could not be attained in a single year; it will be regulated and controlled by the number of excavating units which can be installed with auxiliary appliances and facilities.

It is probable, therefore, that the output can be increased from year to year until the maximum number of excavating units is installed that it is possible to work at any one time. It will be three years at the least before this can be accomplished. Even after the maximum number of excavating units is in operation, all things being equal, it is naturally presumed that experience will give increased efficiency to the force, and the actual output will be increased from year to year.

It therefore follows that each succeeding 10,000,000 cubic yards can be excavated at less cost and in less time than the preceding 10,000,000; and it is reasonable to suppose that the amount of excavation annually disposed of, at least after the first five years, will be largely in excess of the average amount disposed of during those years, certainly the first three.

The situation will therefore be that when the material has been excavated from the summit cut necessary for a high-level canal the work will be carried on with the greatest efficiency, rapidity, and economy, and that the time needed to remove the extra material necessary to construct a sea-level or low-level canal can be fairly ascertained by dividing the maximum amount of annual excavation removed during the construction of the high-level plan into the amount remaining to be excavated.

The question of the selection of plans seem more a matter of policy and general judgment than one of engineering. The plans which have been suggested by reputable engineers are possible of execution in some time and at some cost. If the revenue to be derived from the construction and operation of the canal could be fixed with some degree of accuracy or even approximately, and the matter was to be treated as a commercial one, it would be comparatively easy, being simply a point of engineering and commercial judgment, to determine the most suitable plan.

However, as politics, national pride, and world benefits are the real and determining factors, from this view point the situation demands not the cheapest but the best canal, and the only question is how much would the United States be justified in expending on the project.

The writer sees no reason why a sea-level canal could not be completed in ten or twelve years at the most, with the possibility that vessels may be passed through it at the expiration of eight years after plans have been decided upon and preparatory work has been completed. These remarks, however, are based upon the supposition that the work will be conducted upon efficient business principles.

If a monument is to be built to commemorate the spirit of accomplishment of our modern civilization as exemplified in the American people, it should be done in accordance with the best plan and in the best way, and be truly great. The American people should not deceive themselves with the idea that they are making a commercial investment only. If it is to be a monument and a great one, in its proper accomplishment we should not permit consideration to be given to a few additional years' time, or allow the paltry sum of a few million dollars in cost to influence us. What sculptor would shorten the legs of an Apollo to save marble?

SEA-LEVEL PROJECT.

In the consideration of designs for transportation routes the fact that a straight and level line is the most desirable is fundamental, and it would seem even unnecessary to formulate it.

It has been the custom of the writer, in works and designs of this character, to give primary and careful consideration to the most ideal form, and to vary therefrom only so far as to overcome obstacles of a physical, financial, or other nature.

As the ultimate end to be arrived at is the safe and expeditious transportation of traffic at the lowest possible unit cost per ton or per passenger, the plan finally selected was usually the one in which the sum obtained by adding the interest on the cost of construction plus the actual annual cost of maintenance and operation was the minimum.

As financial and commercial conditions are continually changing, the world-wide tendency being toward lower rates of interest and increase in demand for transportation facilities, the engineer who may be called upon to conceive, design, construct, maintain, operate, or manage transportation facilities will be neglectful of his duty if he overlooks them. Therefore, in considering the plan of the Isthmian Canal or any great public work intended to furnish increased facilities for transportation, the feature of future development should not be overlooked, and any variation from the ideal of a straight or sea-level canal should only be made after the most mature and careful consideration and for the gravest of reasons. The burden of proof should most assuredly rest on those who propose deviations from the ideal. Minor deflections from a straight line are of course comparatively immaterial as compared with variations of levels.

In the consideration which the writer has given to a sea-level isthmian canal he does not believe there are any obstacles to be overcome except those which can be measured by time and cost. There is, perchance, a sum which the American people would not be willing to pay for the canal. The question of time is merely one of patience or impatience, considering the fact that it has been approximately five hundred years since the canal idea was first conceived that is now planned, and which should last and benefit mankind not only throughout years but centuries. The American people will certainly be content to wait at least a few years longer to obtain the more perfect and ideal sea-level canal, and there must be some amount which they would be willing to spend for the purpose.

While these are matters which can only find final expression through the actions of the American Congress, they will be controlled largely by the views of your honorable Board as to the time and cost necessary for accomplishment, and upon you rests a most grave responsibility in formulating estimates, plans, and recommendations.

The writer has endeavored to formulate certain propositions which he considers fundamental, and others, while not fundamental, which are essential in arriving at the most desirable plan of canal.

First, a sea-level canal of such dimensions as would afford unrestricted passage for the largest vessels afloat, with such margin for increase in size and draft for future vessels as can reasonably be anticipated, making allowances for unexpected developments, is most desirable.

Therefore it seems fundamental that the type of canal to be adopted should permit of economical enlargement in all of its dimensions, and that no plan should be decided upon which would prevent the ultimate construction of a sea-level canal at least approximately approaching to the final idea of the Straits of Panama. Hence, the questions of time and cost should be considered to the extreme limit before determining upon a plan which would interfere with this ultimately desirable accomplishment.

In case, however, the elements of time and cost are such potent factors as to debar the sea-level project, it would seem fundamentally desirable that the idea should not be departed from to such an extent as to prevent its ultimate accomplishment, and no further than would bring the cost and time of completion inside of maximum limits which may be determined upon.

In the construction of dams or barrages for the control of the flood waters of various streams, or the formation of intermediate lakes for the purpose of navigation, it is highly desirable that no dams should be constructed the foundations of which can not be carried to bed rock, or at least impervious curtain connection be made therewith. No high dam should be constructed the destruction of which, by accident or design, would close navigation through the canal until its restoration. If it is absolutely essential to the project that such dams be constructed they should retain the lowest possible head of water and be of such a nature as not to require the use of experimental, new, or untried methods of construction.

In the consideration of that class of plans involving terminal lakes controlled by low barrages, the uncertainties of a foundation on the soft alluvial soil of a river deltage should not be overlooked, and these dams should be as low as possible, imposing the minimum weight upon the subsoil, and be of the shortest possible length.

In taking soundings in the harbor of Colon a railroad bar would frequently sink of its own weight to a depth of 50 feet below sea level, passing through from 10 to 40 feet of mud, dependent

upon the depth of the water. The same conditions exist in a large part of the Rio Grande delta, and the construction of even a low barrage would undoubtedly encounter innumerable difficuties in crossing localities where the subformation would be such as to give way under the imposition of the weight of the material placed thereon. The same obstacle would probably be met to a greater or less extent in the construction of a dam, particularly a high one, in the vicinity of Gatun. The entire valley to at least a depth of 200 feet is alluvial. It is, therefore, highly improbable that in the heterogeneous mass of material with which the ancient gorge is filled, particularly near the surface, that unforeseen difficulties in securing proper foundations would not be encountered.

Coming to Bohio, while it is not impracticable to construct a dam at this locality, the fact that bed rock was found at a point 167 feet below sea level, overlaid at the greater depth by material of a freely water-bearing nature, renders the construction at this site undesirable. Though possible, it involves experimental methods, the cost and result of which are as yet undetermined quantities.

In the opinion of the writer, the Gamboa dam furnishes the key to a practicable solution of the problem, and while an absolutely necessary adjunct to the sea-level project, it will also fit in with any low-level lock plan not involving the creation of an intermediate navigable lake of such size as to afford absolute control of the Chagres and other floods. Should even a plan be adopted for approximately a 50 or 60 foot summit-level elevation involving a dam at Bohio containing a lake of moderate dimensions, the construction of some dam either at Gamboa or Alhajuela would be necessary; in the opinion of the writer, preferably at Gamboa. This dam would be adjacent to the line of the canal for inspection and regulation, would furnish ample electric power, which should be made available to assist in the construction of the canal and also its maintenance and operation, and afterwards would furnish a water supply and sufficient electrical current to provide for lighting and other public utilities along the route of the canal, including its towns and cities.

The construction of the Gamboa dam would satisfactorily solve the control of the Chagres River, which would resolve itself simply into the question of taking care of and controlling the average and not the maximum floods of the Chagres, properly constructed spillways, supplemented with diversion channels and utilizing the canal prism with its outlets to two oceans, performing this work.

While the construction of a tunnel spillway through the mountain range, or an open cut to act as a natural automatic spillway, discharging the surplus floods into the upper valley of the Gatuncillo on the Caribbean slope, might be desirable, it is not an absolute necessity for the sea-level plan.

The estimates which have heretofore been made for the construction of the Gamboa dam for the control of the Chagres, even including the tunnel spillway and all the diversion channels combined, do not exceed 10 per cent of the cost of even the sea-level canal. In considering the various difficulties which combined make up the time of accomplishment of any engineering work, their relative importance can properly be held to be the percentage such factors bear to the whole; the formula is practically a plus b plus c plus n equals accomplishment. An item in the equation of value not to exceed one-tenth of the whole should certainly not be an absolutely deciding deterrent element.

It may be well to repeat and again emphasize a few factors which the writer considers either essential or desirable:

1. That as a strait at Panama unobstructed would place the least retriction to commerce, the sea-level canal is the ideal plan.

2. No plan should be adopted that would ultimately prevent the completion of a sea-level canal should future demands and necessities require it.

3. No high dam should be constructed the foundations of which can not be carried to bed rock, or an impervious curtain wall constructed practically accomplishing the same purpose.

4. No high dam should be constructed the destruction of which by man or nature would prevent the use of the canal until its restoration had been effected.

5. The construction of dams or barrages on alluvial foundations is undesirable, and this form of construction should be eliminated or reduced to the minimum and contain the least possible head of water.

The writer has heretofore recommended, as contained in his report of February 1, 1905, to the former Isthmian Canal Commission, as follows:

> Therefore it is recommended that no temporary or tentative plan be adopted that will interfere with the final adoption of the "sea-level plan," which it is hoped will ultimately receive the favorable consideration of the Commission.

And the above recommendation is repeated to your honorable Board.

GENERAL PLAN AND METHODS OF CONSTRUCTION—UNIT COSTS AND TIME.

The writer recommends the favorable consideration of the harbor facilities at Colon suggested on page 29 of his printed report to the Isthmian Canal Commission under date of February 1, 1905.

The work of dredging the inner harbor inside of Point Cristobal Colon, and the plan of temporary wharves and docks, was commenced under the direction of the writer and should be carried forward as rapidly as possible. The necessary wharves, docks, warehouses, railroad yards, and track connections should be constructed so as to enable all material for the canal supplies to be delivered and received at this point.

While it is the opinion of the writer that the straight entrance to the canal should be part of the final plan adopted, there will be no necessity for its immediate construction. It should not be constructed until the outer harbor is properly protected by a breakwater. The situation and conditions which prevail at Colon during the continuance of what is known as "northers" are such as can not be adequately described in words. The suddenness with which these northers come, practically in an hour without warning, and their severity, are such that the conditions can not be appreciated except by personal observation.

The final plan should provide for an outer harbor properly protected by a breakwater, and a straight entrance therefrom to the canal westward of the inner harbor which it is necessary to create for immediate use. This straight entrance, however, must be protected from the open sea in the manner suggested by the Engineering Committee of the former Commission.

From the inner harbor along the canal axis the writer would recommend that the method of construction and form of section consist of throwing up embankments on each side of the canal axis with either the dipper or clam-shell dredge and parallel to the canal axis, leaving a berm of reasonable width between the bank of the canal proper and the foot of the proposed levee or embankment.

This process of construction should continue as far inland as it is possible to do the work by dredging. In the lower reaches of the canal the section should be completed by the use of hydraulic dredges, excavating and pumping over the embankment all excavated material.

The embankment will serve three purposes:

1. To keep flood waters out of the canal section.

2. To retain the material excavated from the canal by hydraulic dredges and prevent it reentering the canal section.

3. To provide a roadbed for the Panama Railroad, which should be carried along the embankment on the east side of the canal to the entrance of the principal excavation through the continental divide, where it should be located upon the 50-foot berm which has been suggested by the writer.

In case a sea-level canal is decided upon, this embankment should be carried as far inland as possible, although it may be necessary to cut through the points of higher ground in order to provide and take care of a diversion channel on each side of the canal axis, on the land side of the levee.

Through the central excavation the maintenance of railroad tracks on the berm of the canal will furnish the means for the removal of such débris as may fall from the sides of the excavation

and accumulate on this berm, preventing its entrance into the regular canal section. The location of the railroad on this embankment will do away with the construction and maintenance of bridges, except in such places as it may be necessary to connect the diversion channels with the canal axis in order to admit the surplus water from the Gamboa dam or from other sources into the canal section.

In the opinion of the writer the operation of the canal will increase rather than diminish the necessity for railroad communication across the Isthmus, and between Colon and Panama and intermediate towns. This line, however, should be operated with electrical power, which can be furnished from the Gamboa dam.

It may also be advisable to construct a single-track railroad through the central excavation and along a portion of the embankment thrown up on the west side of the canal for use in its maintenance.

The dredgable section through the lowland between La Boca and Miraflores should also be constructed in the same manner.

While the work of dredging the two ends of the canal can be quickly and economically performed it would be of great advantage in the general handling of the work to have these two end sections completed as soon as possible, in order that dredges might work as far inland as practicable to assist in the attack on the principal excavation through the divide. This work can be performed by dipper dredges of from 5 to 10 cubic yards in capacity, loading the material on seagoing barges, and dumping it in deep water beyond the harbor limits.

The cost of the dredgable work, including plant, should not exceed a maximum of 20 cents per cubic yard for the soft dredgable material, varying from 10 cents where it can be pumped by hydraulic dredges over the embankment to 20 cents where it is necessary to load it in barges and subject it to the extreme haul seaward.

The various compact clays which will be encountered in places, and at times have been considered and classified as rock, will be easily dredgable, at least with modern clam-shell or dipper dredges, and so far as the dredging is concerned, after they are broken up by blasting, should not exceed 10 or 12 cents per cubic yard. The extra cost of this work will be due entirely to the amount of money spent in blasting.

As the work of boring will be handled by machinery and will not necessitate drilling, but be done by augers driven with power and working in gangs, the principal cost will be in explosives. This work should be performed at not to exceed 50 cents per cubic yard.

The small amount of coral rock encountered may possibly exceed this in cost, although in the opinion of the writer it should be removed with powerful dredges for less than 50 cents per cubic yard. In driving the piles for the wharves in Cristobal Colon, wooden piles were driven through this coral without great difficulty. Where encountered in the canal section, while of various thickness, it was generally underlaid with soft material, and its removal should not be difficult.

In order to construct a sea-level canal and excavate to the elevation of 40 feet below the sea level, some basaltic and trap rock may be encountered, and in other places a small amount of limestone, sandstone, or conglomerate. The removal of this rock outside of that encountered in the central excavation will doubtless vary from $2 to $5 a cubic yard in cost, dependent upon the local conditions. That encountered in the central location below sea level, if the work is conducted upon proper lines, will probably cost from $1 to $2 per cubic yard; but as the amount is limited the extra cost will doubtless be absorbed in the general estimate for the central excavation.

The limit of time that it will require to complete the canal or put it in operation will depend upon the removal of the eight miles of central excavation, containing approximately 100,000,000 cubic yards, this being based on Mr. Dose's estimate of a canal section averaging 200 feet in bottom width, 50-foot berms, and slopes 1 to 1.

The time required to do this work is dependent upon the excavating units which can be installed and the capacity per unit, which in turn is dependent upon the promptness with which empty cars are furnished to the steam shovels and loaded cars removed. The efficiency of the

entire operation rests upon the plan of tracks, the quality and amount of motive power, the number, capacity, and character of the cars, the provision of adequate and proper dumps, and dumping facilities. The limit of the capacity of the steam shovels will practically be determined by the efficiency of the personnel of the organization conducting the work and the adequacy of the equipment.

The writer sees no reason why the following scheme of progress is not practical and conservative:

There are now on the ground, and should be in active operation by the 1st of January, 1906, at least 10 steam shovels. From that time on it should be reasonably possible to furnish and install an average of at least 24 steam shovels per annum. Even under the restrictions of the eight-hour day these steam shovels, even in large numbers, should average 200,000 cubic yards of excavation per annum at least.

This estimate is based on 800 cubic yards per day of twenty-one working days in the month. These 10 steam shovels in operation in 1906 should excavate 2,000,000 cubic yards in one year. The 24 steam shovels installed during the year, on account of the fact that proportionately a greater number will be started during the dry season than later on, should yield a total of 3,000,000 cubic yards, making the total excavation for the year 1906, 5,000,000 cubic yards.

At the commencement of 1907, 34 steam shovels would therefore be in operation, with an annual capacity of 6,800,000 cubic yards. The 24 additional steam shovels installed during the year 1907 would yield 3,000,000 cubic yards, which would make a total for 1907 of 9,800,000 cubic yards of material.

At the beginning of 1908, there would be in operation 58 steam shovels, with an average annual capacity of 11,600,000 cubic yards. The installation of 24 steam shovels in 1908 would make the total output for the year, 14,600,000 cubic yards.

With 82 steam shovels installed and at work at the commencement of 1909, having an annual practical capacity of 16,400,000 cubic yards, which would be the output for the year 1909, at the end of the year there would therefore have been removed from the central excavation 45,800,000 cubic yards.

Continuing this rate of progress during the years 1910, 1911, 1912, and 1913, the amount of the excavation would amount to 111,400,000 cubic yards at the end of eight years from January, 1906.

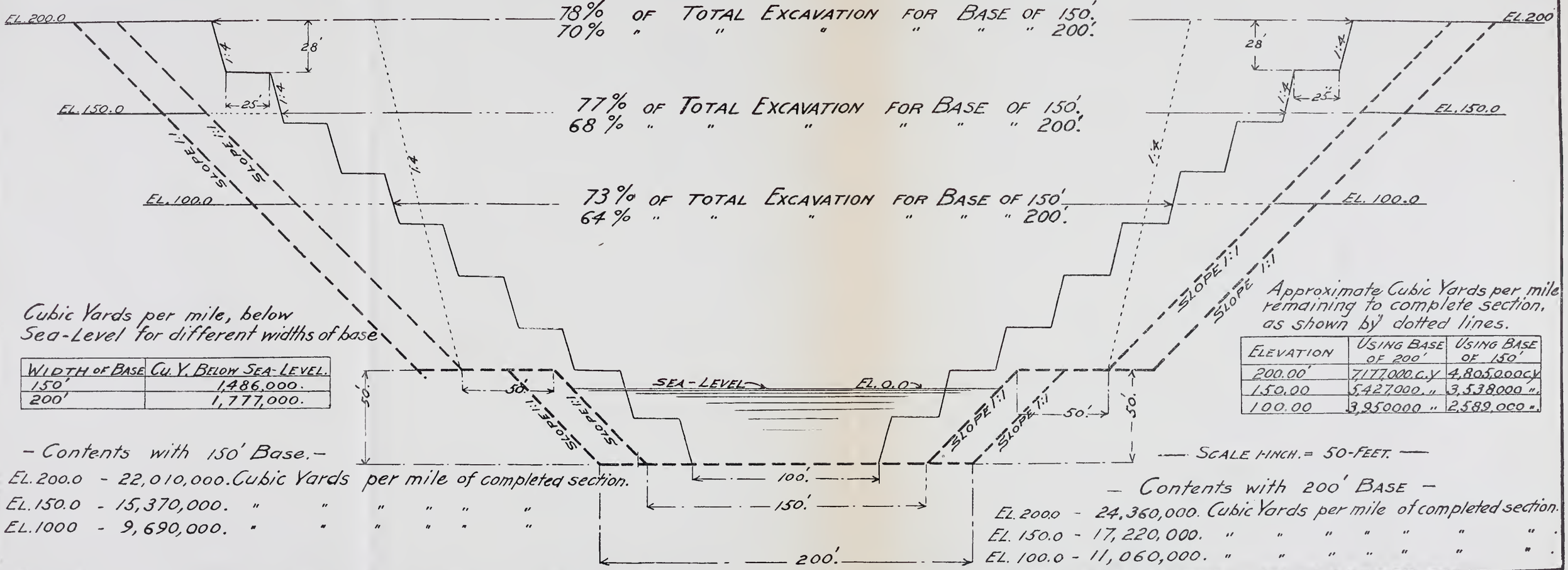
In the meantime the excavation of other portions of the central excavation outside of the eight miles could be carried on partly by steam shovels, partly by the methods used in the construction of the Chicago Drainage Canal, with side dumps where the depth of the excavation and the character and topography of the ground alongside of the canal would admit of this treatment, and by dredging at both ends. It would therefore seem reasonable on this basis, and even discounting these figures 20 per cent, that the canal could be opened for navigation within eight years and completed in ten—at the most in twelve years.

As the actual working capacity of the steam shovels now employed in the Culebra cut, if properly and continuously supplied with cars, is from 400 to 500 cubic yards per hour, varying with the capacity of the machines and the personnel of the men running them, it would seem reasonable and conservative that one-fourth of this capacity should be actually attained as the constant average, although it will of course be necessary to provide a sufficient additional margin of machines to maintain the number constantly at work as herein outlined. Under the practical difficulties at Panama the writer has assumed that 100 machines actually on the Isthmus would yield a constant average working number of at least 82 when the work is under full headway, even under extremely unfavorable conditions. This, of course, does not provide for the additional machines to be engaged on the excavation of that portion of the canal outside of the eight miles of maximum excavation which is used as the basis of this calculation.

By using the terrace method of excavation, with horizontal spacing of, say, 25 feet, giving a width sufficient for two tracks at a perpendicular face of approximately 28 feet, with intermediate slopes of 1 to 4 being used, steam shovels could be worked upon each terrace. For the purpose of calculation, assuming four terraces in each 100 feet of depth of excavation and that

Exhibit A

TYPICAL CROSS-SECTION OF CANAL.



Cubic Yards per mile, below Sea-Level for different widths of base

WIDTH OF BASE	CU. Y. BELOW SEA-LEVEL.
150'	1,486,000.
200'	1,777,000.

Approximate Cubic Yards per mile remaining to complete section, as shown by dotted lines.

ELEVATION	USING BASE OF 200'	USING BASE OF 150'
200.00'	7,177000.c.y	4,805,000c.y
150.00	5,427,000. "	3,538000 ".
100.00	3,950000 "	2,589,000 ".

— Contents with 150' Base. —

EL. 200.0 - 22,010,000. Cubic Yards per mile of completed section.
EL. 150.0 - 15,370,000. " " " " " "
EL. 1000 - 9,690,000. " " " " " "

— SCALE 1-INCH. = 50-FEET. —

— Contents with 200' BASE —

EL. 2000 - 24,360,000. Cubic Yards per mile of completed section.
EL. 150.0 - 17,220,000. " " " " " " " .
EL. 100.0 - 11,060,000. " " " " " " " .

three of these could be used at the same time, leaving one out of the four for workable adjustments, and working three steam shovels to each mile of length, and terracing each side of the excavation, such a plan would permit of the use of 18 steam shovels on each mile of excavation for each 100 feet of depth of cutting. On the assumption that the larger portion of the excavation of the eight miles is concentrated in five miles, this would permit of the simultaneous operation of 90 steam shovels on this five-mile section for each 100 feet of depth of excavation.

Considering the fact that the scheme outlined above will require three years for the installation of the maximum number of 82 constantly working steam shovels, this should be sufficient time to shape up the general work of excavation in such a manner as to permit of the use of the full number of machines, and as they would be engaged on the attack of the excavation at the point of greatest depth at the end of three years, when the full number is established, the conditions should be such as to admit of uniform operations.

It is understood that steam shovels in excess of 24 a year would be installed on other portions of the work on other sections outside of the central section under consideration, this number of 24 being used as it is considered an ample number of machines to install in the central eight-mile heavy section in view of the various difficulties surrounding the work and the fact that each steam shovel will require for loading, switching, main running, and dumping tracks approximately three miles of track, two locomotives, and a sufficient number of cars, unloading apparatus, bank spreaders, and other auxiliary appliances, together with the necessary personnel constituting the general organization, all of which, however, should easily be provided at the rate of progress required to install the excavating units.

In connection with this rate of progress there are various elements of flexibility which can be considered. First, the adoption of two or three eight-hour shifts will materially increase the output for twenty-four hours. More shovels than those enumerated in the above schedule could be installed and operated. Efficient management, such as a contractor would give the work, should and would materially increase the efficiency of the entire organization and consequently of the excavating units, increasing output.

These remarks and conclusions are all based on the assumption that the men and material necessary for this work will be promptly furnished as required and the work conducted in accordance with ordinary business methods; in other words, as by a contractor having ample means and full facilities at his command.

At Culebra proper and at Emperador, and possibly at other points along the canal where the basaltic rock exists, slopes much steeper than 1 to 1 could be adopted, and consequently a large saving made in the most expensive and hardest class of material to be removed and at the point where the greatest number of yards to be excavated is now concentrated.

At other points along the excavation shales and other material will be found which will stand, at least temporarily, at much steeper slopes than 1 to 1, and it certainly would not be necessary to remove the entire cross section back to a 1 to 1 slope prior to the opening of the canal for navigation. This process could be spread over several years after the opening of the canal.

Herewith is submitted a sketch marked "Exhibit A," showing some typical cross sections on the terrace plan.

This attached sketch is of course simply a tentative cross section. It has not been considered necessary for this purpose to go into the full details of the readjustment of these slopes which may be necessary at various points along the line, to be determined by the character of the material in each separate locality. At some points a heavy retaining wall may be necessary; at others it may be sufficient to break the submerged slope with an intermediate berm at, say, 10 feet below low water, or at such a point as would be sufficiently below the surface as not to be affected by wave action, and to riprap this bench and slope above it; or it may be necessary to carry this paving to the extreme depth of section where the material is liable to be washed by current action. With the use of the 50-foot berm to serve the purpose so that a retaining wall would not have to support a surcharged embankment, an economical method of slope protection might be the covering of the slope with a moderate layer of concrete. At other places it might

be necessary to construct retaining walls to support the canal face of the berm. These adjustments would naturally affect the ultimate cross section, as it was the intention of the writer to sink the central portion of the excavation to the extreme depth before excavating the sides to the extreme width. It was considered that the character of the material could be determined upon before the full section had been completed, and such treatment be given the slopes in various localities as the local conditions might require. An examination of the attached section will show how this can be accomplished.

Assuming an average elevation of 200 feet through the central portion of the divide, it will be noted that a temporary section 100 feet wide at the bottom, 40 feet below sea level, with terraces of 25 feet horizontal and 28 feet rise, with 1 in 4 side slopes, can be constructed by removing 78 per cent of the total excavation required for a section 100 feet in bottom width and 70 per cent of a section of 200 feet, leaving the full construction of the 50-foot berms for completion after the opening of the canal to traffic.

Under more favorable conditions than those enumerated above there is a possibility of being able to accomplish this work in less than eight years, but in view of the many contingencies which arise in large works of this character it might not be wise to indicate that this might be accomplished.

During the year the writer had careful examinations and reports made on various dumping grounds and their capacity, and also gave personal consideration to this most important question.

The dumping grounds and tracks as they exist to-day are practically those located and used by the French company. Lack of track material, labor, and other appliances prevented any material changes being made in the track arrangements, and only such were made as were necessary to connect up and improve existing systems, including minor changes to add to the flexibility of movements. The writer's plan in general terms consisted of finally having four distinct main-track railway systems leading from the excavation to distant spoil banks, two at each end of the central excavation and one on each side of the canal axis; these track systems to consist of two or more main running tracks as requirements might determine, using the Panama Railroad as a base; first, to provide a double track for this service, and, second, to provide additional tracks along its right of way for the purpose of removing excavated material from the central cut.

Part of this plan consisted of a main double-track railroad leading from the Culebra excavation to the Gamboa dam site, over which excavated material could be delivered at the site of the dam for construction purposes.

On the west slope it was intended to construct a double-track railroad in connection with the Panama Railroad line for the handling of excavated material for disposal on the flats between Miraflores and La Boca, and also to construct a main double-track system along the west bank of the canal to some general locality to fill in the ground between the canal axis and the foothills. These main-track railroad systems should be ballasted with broken stone and maintained in first-class condition to provide for rapidity of movement.

Ample side-track facilities should be constructed in the vicinity of the dumps, and excavation for the storage of loaded and empty cars. At each steam shovel, double tracks should be provided and the work so arranged that under no circumstances should it be necessary for a steam shovel to wait for empty cars. An abundance of car equipment should be provided so that in case of derailments, delay at dumps, rainy weather, or other cause, there should be no reason why the steam shovels should not be maintained at continuous work. As the rate of progress depends primarily upon the number of cubic yards loaded by the excavating units per day, all other parts and functions of the work should be regular to achieve this end.

At the dumps numerous long tracks should be provided, so arranged that in case of necessity for repairs of tracks and accidents on one dump track the other would be immediately available.

The question of the use of a high dump with infrequent track movements, or of a low dump and frequent movement of tracks, should have the most serious consideration. In the opinion of the writer low dumps spread over a wide area can be more easily and economically operated than high dumps covering a small area. The settlement on the low dump is much less in proportion to the height. A few inches of track settlement on the low dump can be easily adjusted

without material injury to the tracks, while the unequal settlement and sloughing off in high dumps cause track repairs to be slow and expensive and materially delay the work. Properly arranged dumps over a wide area will enable the material to be suitably assorted. One of the difficulties heretofore encountered with the dumps has been the fact that rock and shales have been placed on the sides of high dumps of clay, causing serious sloughing and settlement due to the weight of the rock and the unstable character of the clay beneath. When the dumps are low they may be entirely of rock or shales. With the use of flat cars and proper spreading apparatus no serious difficulty need be apprehended from the settlement of dumps.

As to the location of dumps, it is well to note that the cost of transportation for each additional mile after the first mile should not exceed two-tenths of 1 cent per mile per cubic yard; in other words, after the first mile, an extra haul of 10 miles should cost but 2 cents per cubic yard for transportation alone.

In the preparatory work the first step necessary is to remove during the dry season the slippery clay formation which overlies the Culebra excavation. If this blanket of clay is removed a safe distance and is properly drained, in the opinion of the writer no serious trouble will be afterwards experienced with slides which can not be properly controlled.

Central drainage excavations should be made from both ends of the cut in order to give ample drainage at the lower elevations, and all of the barriers heretofore existing should be removed and the cut opened through from end to end, except where necessary to cross to form connection with the work on each side. This should be done with suitable bridges, which should not prevent continuous excavation of the material underneath.

Extraordinary efforts should be concentrated on the sinking of the central excavation to the greatest possible depth. If this is accomplished and kept well in advance of the remainder of the work the output will not be diminished or the cost increased as the work progresses until the central excavation has at least arrived at such a depth that drainage by gravity is impossible and pumping may be required; this applies to that section below the plane of 10 feet above sea level.

If the entire width of the excavation was removed through each succeeding 100 feet of elevation, the section would of course be narrowed and the work limited, but properly adjusting the work and keeping a central ditch excavated in advance of other work will increase rather than diminish the capacity of excavation as the work progresses.

It is understood that the two principal factors which your Board desires to determine are the unit costs and the elements of time.

As the central five or eight miles of excavation through the continental divide is the crux of the whole subject, the substance of the writer's foregoing remarks is that he considers the net cost of this work can safely be taken on the grand average of 50 cents plus 20 per cent for contingencies or contractor's profits, making 60 cents per cubic yard.

While mere perfunctory management of the work with inefficient control might increase the cost, on the other hand it is possible, owing to the great amount of material to be removed, with efficient management and the use of the best machinery, and competent personnel inspired with the zeal of emulation, to materially reduce this cost.

From the writer's experience on the Isthmus and elsewhere he feels warranted in recommending the adoption of 60 cents per cubic yard. This increase over and above the prices recommended by him on page 22 of the Report of the Chief Engineer, dated February 1, 1905, has been brought about largely by the adoption of the eight-hour day and by the conclusion which he has also reached that to obtain efficient and economical results it will probably be necessary to contract this work, on account of the delays and difficulties which surround the prosecution of work the details of which are carried on under direct Government control.

Reference has not been made to the cost of other factors of the work, as estimates previously made have been based on unit prices used by the first Walker Commission, which were thoroughly considered and seemed to be liberal enough to cover all ordinary contingencies. It is of course assumed that any estimate made for this work must be approximate and should be ample to cover all ordinary contingencies, but as numerous unforeseen conditions will be continually arising

during the work, making necessary changes in detailed plans, and possible economies may present themselves, it is unwise and unnecessary to go into details any further than to arrive at approximate results. The details of both plans and methods can be safely and should properly be left for the engineering force in immediate charge of the work during its progress to solve.

NOTES ON THE REPORT OF THE CHIEF ENGINEER, ISTHMIAN CANAL COMMISSION.

[In reply to the memorandum of Gen. Peter C. Hains on this subject. Estimates, page 28.]

In the fifth item, referring to the Bohio locks and spillway, the word "spillway" should not have been used. In the first draft of this estimate this caption was used to designate this item, but the dam was not specifically mentioned. In discussing this item in reference to the 60-foot level with Gen. George W. Davis, Mr. Wm. Hubert Burr, and Mr. Wm. Barclay Parsons, the gentlemen who constituted the Engineering Committee, it was considered that the item was not large enough to cover the Bohio locks, dam, and spillway, and the committee at that time thought it wise and conservative to place the estimate for item 6, the Bohio dam and spillway, at $5,000,000, in addition to the estimate for Bohio locks.

In reference to item 7, excavation Bohio to Miraflores, 250,000,000 cubic yards was the grand total of Mr. Bertoncini's estimates of the amount to be excavated between kilometers 25 and 62, on the basis of a sea-level canal section 40 feet below sea level, of 200 feet bottom width, for the berms 50 feet in width 10 feet above sea level, slopes 1 to 1 above sea level and 2 to 1 below.

This figure of 250,000,000 cubic yards also included an additional amount of 10 per cent added to make provision for slides and unexpected contingencies, experience in actual practice having developed the fact that slides, change of plan, and other elements, as a rule, tend to increase quantities over estimated quantities, whereas the price bid for contract work is generally below units of cost taken by engineers in their estimates.

It is of course absolutely impossible to foresee the exact conditions which would exist upon the completion of the canal section; and, therefore, the estimates made upon this section were merely tentative, the width of the berm being increased or decreased in special localities, as the nature of the material or circumstances might require. The canal section would, of course, vary, whether on a tangent or curve; also variations would be necessary, depending on the plans used in treating the matter of slopes—by use of retaining walls, pavements, or concrete covers on flatter slopes. These details should be left for future consideration during the progress of the work.

As this estimate was required on short notice and the information was not at hand to determine all the elements herein mentioned and others which might afterwards suggest themselves, it was only necessary to decide on a tentative approximate section upon which a general estimate could be based for comparative purposes, and considering all the contingencies it was thought wise at the time to consider outside maximum quantities.

If, in the opinion of the Board of Consulting Engineers for the Panama Canal, a narrower or more reduced section is admissible and practicable, the quantities contained in the chief engineer's estimates of February 1, 1905, would, of course, be reduced.

The question of increase in the width of the berm, or increase in the width of the canal section due to the construction of the retaining wall through the Culebra cut, was not to be finally determined at this time, and it was considered that the wise course to pursue was to treat the estimate in a liberal way.

With reference to the twelfth item, the Chagres and Gatun diversion, there were not data at hand to make a careful detailed estimate of this work. It was considered that the Gamboa location was the most practicable one for a dam for either a sea-level, 30-foot, or 60-foot project, and as it contemplated giving thorough future consideration to the question of the advisability of changing the location of the locks in the 60-foot project, which would terminate the 60-foot level section at Obispo instead of Bohio, and which would naturally increase the expense of the Chagres diversion, it was thought wise for the purpose of arriving at an approximate estimate to make no change in the diversion quantity.

In reference to the Report of the Chief Engineer, Isthmian Canal Commission, February 1, 1905, and the estimates contained therein, it should be remembered that this was in the nature of an emergency report called for on short notice during the visit of the Engineering Committee to the Isthmus at that time.

The various estimates were only made after consideration and general discussion with the Engineering Committee—General Davis, Mr. Burr, and Mr. Parsons—and it was the intention that the estimates should be conservative and ample to cover all possible contingencies. It might also be stated that outside of the estimates for the excavation between Bohio and Miraflores, and the Gamboa dam and spillway, all other items were so far as possible based upon the estimates and the unit prices of the former Walker Isthmian Canal Commission, modified to suit changed conditions.

MEMORANDUM BY MR. JOHN F. WALLACE ACCOMPANYING DIAGRAMS ILLUSTRATING TENTATIVE METHOD OF CULEBRA EXCAVATION.

Herewith are seven diagrams illustrating a tentative method of working the mile in which the maximum excavation exists at Culebra:

Diagram 1 is an average maximum cross section and shows in numbers and colors the different phases of steam-shovel progress.

Diagram 2 shows the "A" and "B" sections at kilometer 54.74 on the line of the maximum cross section above elevation 185 with the different phases in colors and numbers.

Diagram 3 is a progress diagram showing the relative positions, horizontally, of the different steam shovels which may be installed at elevation 185 and below. It also shows the time of entering and the completion of each phase of the work.

These diagrams are not put forward as an exact plan to be followed, but simply to illustrate the process of devising such a workable plan as the engineer in charge may desire, and should be regarded only as a tentative basic study.

The sections shown on diagram 2, and also that part of diagram 1 above elevation 185, as indicated by the letter "C," maintain the form shown on the exhibits only for a portion of the section. That part, however, of the average maximum section (diagram 1) below elevation 185, will remain throughout the entire length of the mile section substantially as shown by the exhibit.

The phases above elevation 185, being masses "A," "B," and "C" (diagrams 1 and 2), can and should be removed before the excavation of the central portion of the average maximum section below elevation 185, as they progress transversely to such an extent as to cause no interference, and they have therefore been given a separate system of numbers.

In accordance with this scheme it is presumed that the sections designated by the same letter or number should be removed approximately simultaneously on each half-mile length, and that the phases designated by the low numbers should of course be removed before commencing on the sections designated by the higher numbers.

It will probably not be found necessary to excavate back to a 1 to 1 slope, as shown on the diagram (diagram 2), for that section west of the center line and above elevation 185. This section is intended to show the maximum amount which, in the opinion of the writer, will require removal.

It is presumed that rock at the greatest depth of the central excavation will stand at a much steeper slope than shown in the diagrams. If this is the case, new slopes which will diminish the amount of excavation may be introduced at such points as the engineer in charge may deem advisable.

In the memorandum of quantities which has been furnished the writer, he notes that on the assumption of a bottom width of 200 feet at an elevation of 40 feet below sea level, with berms on each side of 50 feet and side slopes of an average of 1 to 1 from that point to the top of the excavation, there exists approximately 1,200,000 cubic yards of clay above an average elevation of 290 feet above sea level. This is the clay formation that heretofore furnished the material for slides on the east side of the excavation and north of the maximum cutting at Culebra, which the writer commenced to remove during the dry season of 1904–5 while he occupied the position of chief engineer. The remainder of this material can be removed during the next two dry seasons at least, completing this portion of the work by April 1, 1907, without interference with the general scheme of excavation and far enough in advance thereof to remove any danger of slides from this class of material.

The material from an elevation of 290 feet down to 185 feet consists of shales and of a formation which, in the opinion of the writer, can be maintained in terrace form of intermediate slopes of 4 on 1.

Ten months will be available for the removal of the clay above an elevation of 290 feet on the east side and north of Culebra summit if done during the two dry seasons or semidry seasons between December and May 1 of the two years before mentioned, during which time, on account of the dry season, steam shovels should easily average 20,000 cubic yards of material per month per shovel, each shovel averaging 100,000 cubic yards during each of the two dry seasons.

To accomplish this amount of work in this time would require the assignment of six shovels, provided they can work in this particular part of the cut satisfactorily, for only five months in each of the two years.

However, the larger amount of sliding clay is in the vicinity of Cucaracha, on the east side and at the south end of Culebra cut proper. This consists of a blanket of stiff clay, in which are embedded bowlders, which lies upon a bed of fire clay or soapstone formation which exists on top of the solid rock. When saturated, this mass moves down toward the bed of the Rio Grande toward the central axis of the canal.

In the writer's opinion special arrangements should be made for the removal of this superimposed sliding clay and it should be taken out in a quantity in excess of the cross section requirements in that locality, and systematic arrangements should be perfected for working in this vicinity and taking out this material during the dry seasons in connection with a system of drainage, so as to prevent its entering the canal prism and interfering with the work at the lower elevations. This, however, should be taken care of independently and irrespective of the rate of progress made on the maximum mile of the excavation. About 3,000,000 yards of this material now requires removal.

Diagram 3 is a progress diagram which shows the relative positions of the different steam shovels which may be installed at elevation 185 and below. This series of shovels moving through the half mile will approximately complete the section except so far as it may require modifications to give the final slope. It will be noted from this diagram that the shovels will follow each other at intervals of one-half mile and will follow each other successively, those in advance passing out of the half-mile stretch, their functions being completed, and others entering to take their places.

The shovels at the higher elevations will of course only have to proceed far enough to excavate the material on the plane on which they are at work. Taking the mile of deepest excavation, shovels would start in at the elevation of 185, which on the central line will only give a short distance to be excavated. The following shovels at a lower elevation will have a greater distance to move.

The shovels started at the higher elevation should work toward each other, and when the phases at which they are at work are completed they will of course be eliminated and returned to work in other localities on other phases of the excavation.

The pilot excavators in the central cut should be pushed forward at each end of it at different elevations, in order to afford the necessary drainage channels and to permit of the opening up of the work for the succeeding phases.

These diagrams were made on the basis of each shovel cutting out an area of 30 feet in width by 25 feet in height, with a daily capacity of 1,000 cubic yards, working twenty days in each month. On this basis each shovel advances 35.7 linear feet in one day and 714 linear feet in one month of twenty working days. The rate of progress for each half-mile phase has been considered to be four months.

Diagrams 4 to 7, inclusive, are diagrams showing a suggested arrangement of tracks and shovels covering the first five phases of the work below elevation 185.

The space between the different phases is one-half mile, which is considered sufficient to provide the necessary track space for the working of the shovels, each shovel being provided with two tracks, a running track and a track upon which the empty and loaded cars are placed.

This distance between the phases is also such that there should be room enough for the necessary track adjustments as the work progresses.

Switching can be so arranged, whether one shift or more is worked in each twenty-four hours, that each shovel will be supplied with a sufficient number of cars to last during the entire half shift, particularly if the long noon hour as at present is maintained, and tracks and cars should be provided of a capacity to permit of this being done.

It is of course understood that the progress diagram is only tentative, and that the ability to carry the work out on these lines depends on many complicated factors, and the ability to work to a scheme of this character depends upon their proper coordination. Allowance should be made for the failure of various factors that properly coordinate. Should the average amount excavated by each shovel be less than 1,000 cubic yards per day per month of twenty working days, additional time will of course be necessary. Should the average efficiency of the excavating machines be increased, the time would be shortened. It will be noted that the work on the maximum half-mile section can be completed in approximately nine years. This time would be lengthened or shortened dependent upon the efficiency or inefficiency with which the work is handled.

According to this plan three years would elapse from January 1, 1906, before it would be necessary to employ the maximum average number of steam shovels on each section, and from 1909 eight shovels would be engaged on each half-mile section, which would make 16 on each mile, being 80 steam shovels on the central heaviest five-mile section. The maximum number of shovels would be employed for eighteen months to two years, from which time the number necessary for the work would be gradually diminished.

The progress diagram in the plan of course does not show the shovels which would be at work removing material on the sides of Culebra proper above an elevation of 185 feet, which an analysis of the sectional diagram will show can easily be removed in such a way as not to interfere with the progress below elevation 185, this maximum excavation practically being confined to one-half mile, the crux of the work consisting of the sinking of the central excavation.

The efficiency of the whole work as far as progress is concerned will depend largely upon the ability to keep the lowest central excavation in advance of the remainder. In the opinion of the writer it should be easily within the range of practicability to maintain the average results indicated in these diagrams, and to so organize and control the force as to provide for an efficiency which will permit this to be done.

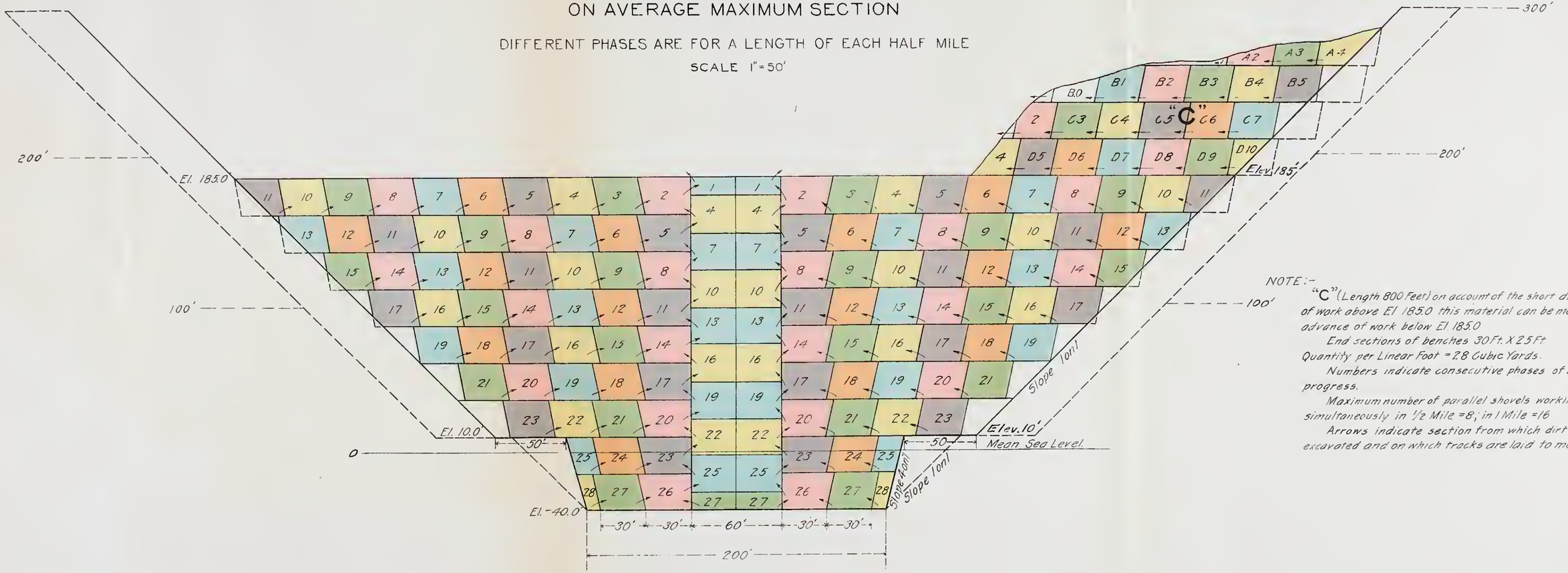
Few American contractors would be content to conduct this work only on a basis of an average of twenty working days in the month and only one shift per day, but would endeavor to form an organization which would yield a much higher rate of efficiency than shown by the conservative data used as a basis for these diagrams and which are considerably within the scope of attainable results.

Diagram No. 1

STEAM SHOVEL PROGRESS
ON AVERAGE MAXIMUM SECTION

DIFFERENT PHASES ARE FOR A LENGTH OF EACH HALF MILE

SCALE 1"=50'



NOTE:-

"C" (Length 800 Feet) on account of the short distance of work above El 185.0 this material can be moved in advance of work below El 185.0

End sections of benches 30 Ft. X 25 Ft. Quantity per Linear Foot = 28 Cubic Yards.

Numbers indicate consecutive phases of shovel progress.

Maximum number of parallel shovels working simultaneously in 1/2 Mile = 8; in 1 Mile = 16

Arrows indicate section from which dirt is excavated and on which tracks are laid to move it.

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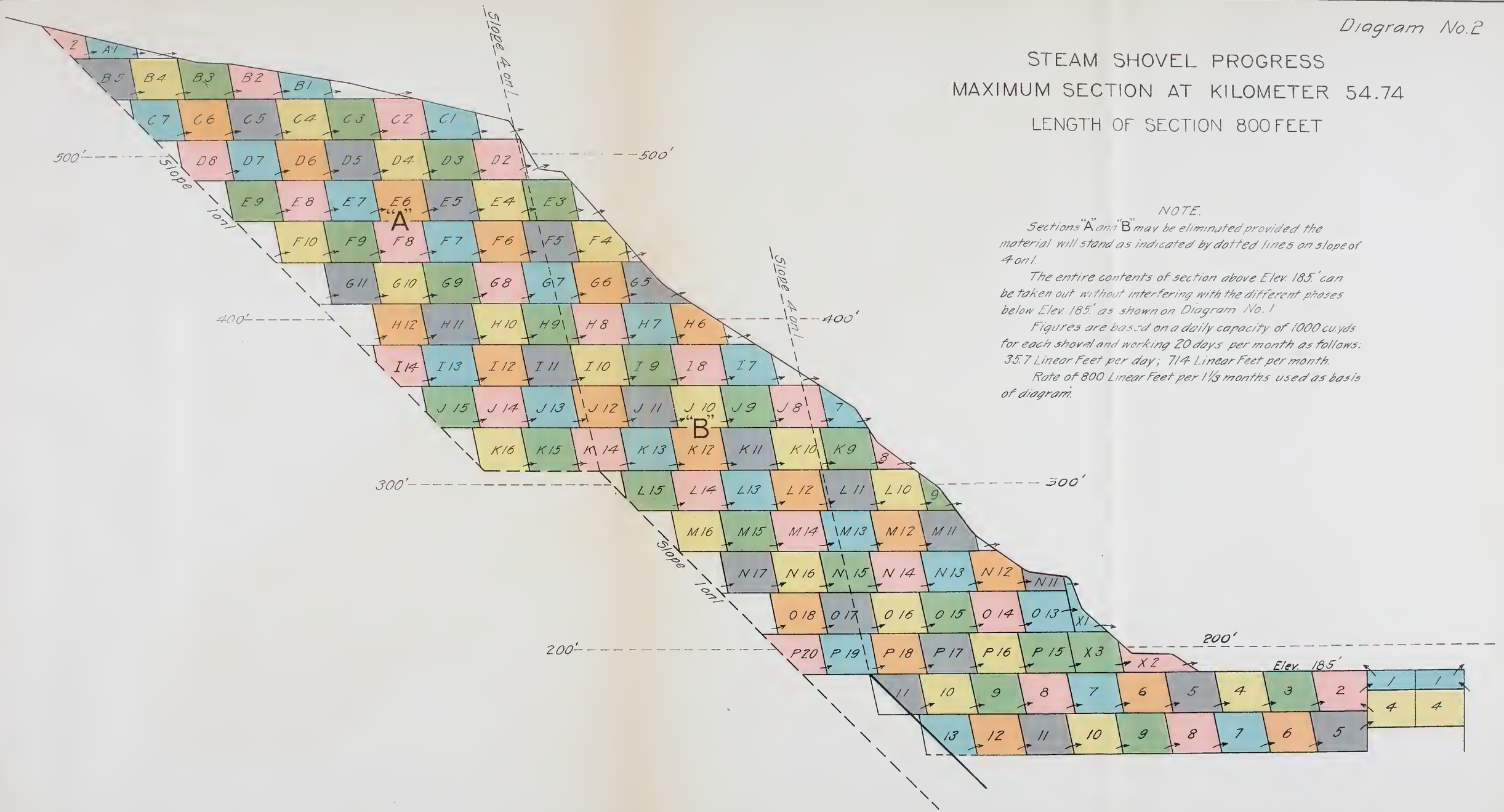
Diagram No. 2

STEAM SHOVEL PROGRESS
MAXIMUM SECTION AT KILOMETER 54.74
LENGTH OF SECTION 800 FEET



NOTE.

Sections "A" and "B" may be eliminated provided the material will stand as indicated by dotted lines on slope of 4 on 1.

The entire contents of section above Elev. 185.' can be taken out without interfering with the different phases below Elev. 185.' as shown on Diagram No. 1

Figures are based on a daily capacity of 1000 cu. yds. for each shoval and working 20 days per month as follows: 35.7 Linear Feet per day; 714 Linear Feet per month.

Rate of 800 Linear Feet per 1 1/3 months used as basis of diagram.

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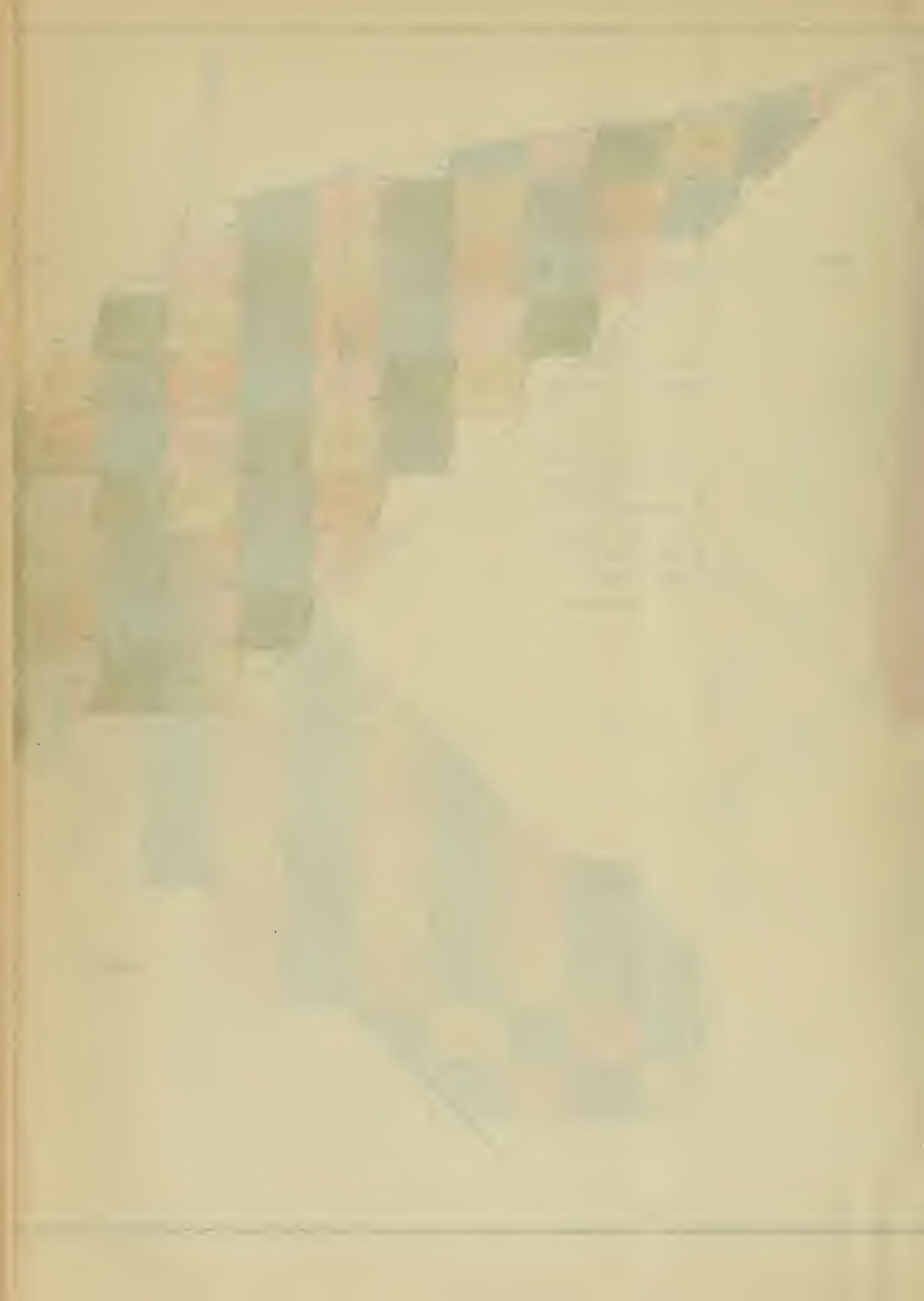
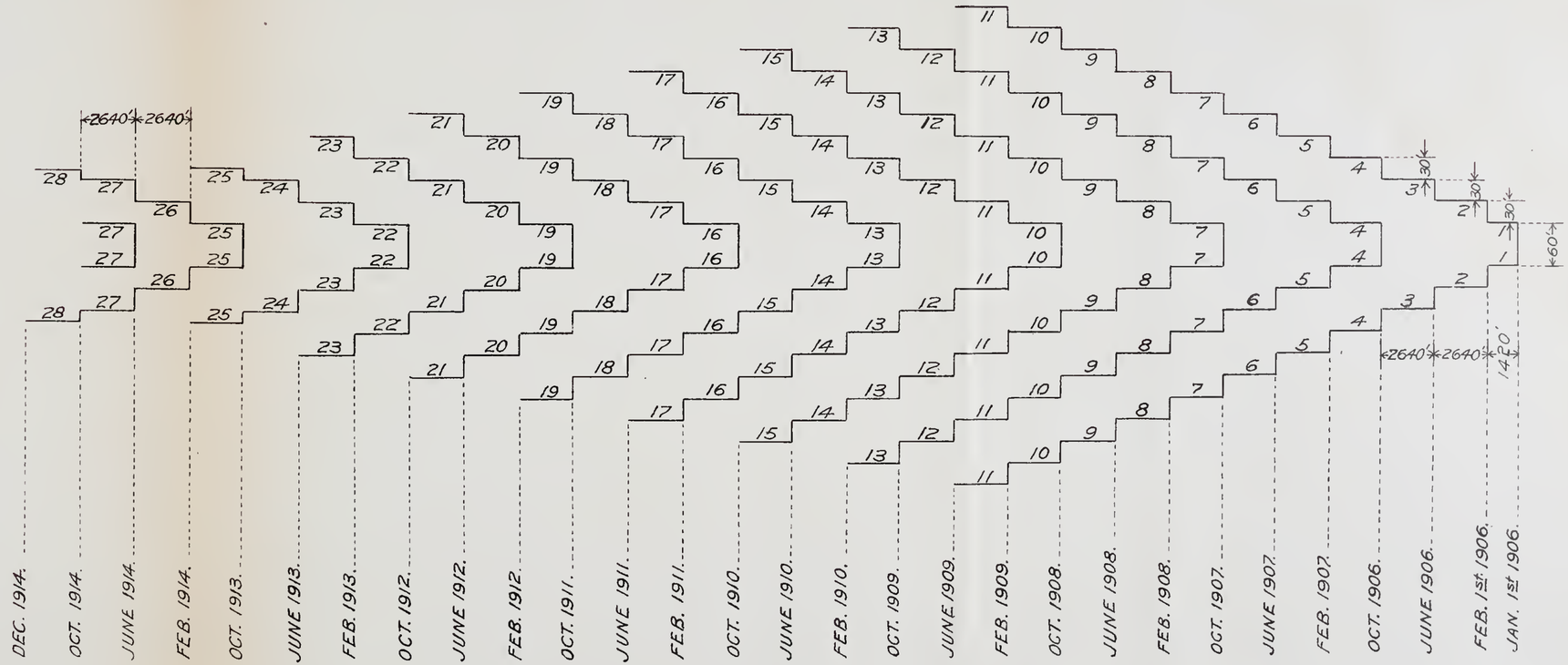


PROGRESS DIAGRAM

Showing Maximum and Minimum Number of Steam Shovels at Work in the Different Phases through 2640 ft. (½ Mile)



NOTE.

Numbers indicate shovels in different phases.
Calculations are based on a daily capacity per shovel of 1000 Cu. Yds. and 20 working days per month.
Details of Progress.
35.7 lin. ft. per day. — 714 lin. ft. per month of 20 days.
2640 lin. ft. per 3.7 months.
(Rate of ½ mile in 4 months used as basis of diagram.)

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Diagram No. 4

DIAGRAM OF PROPOSED ARRANGEMENT OF TRACKS. PHASE NO. 1 & 2.

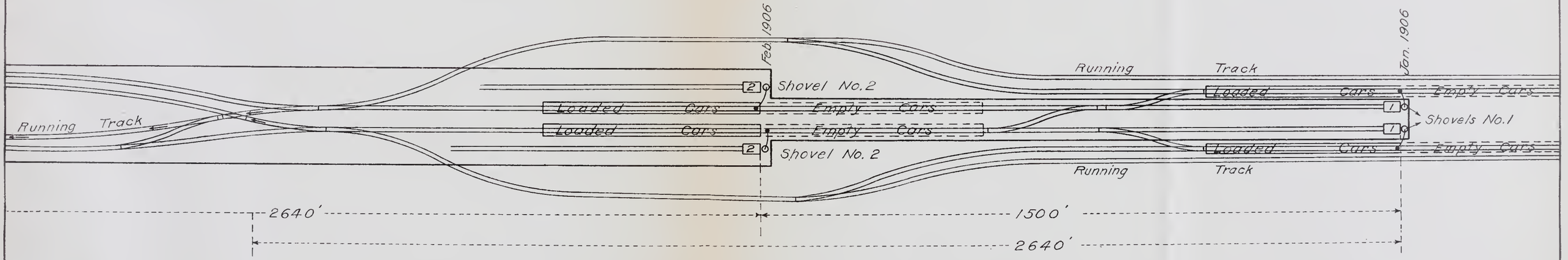

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Diagram No. 5

DIAGRAM OF PROPOSED ARRANGEMENT OF TRACKS. PHASE NO. 3.

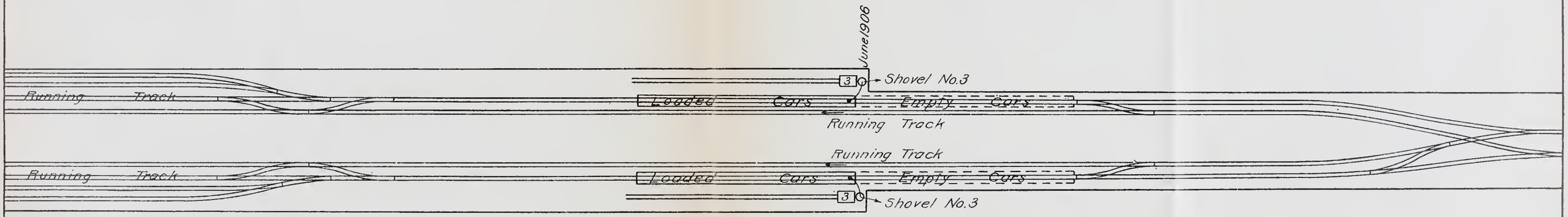

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Diagram No. 6

DIAGRAM OF PROPOSED ARRANGEMENT OF TRACKS. PHASE NO. 4.

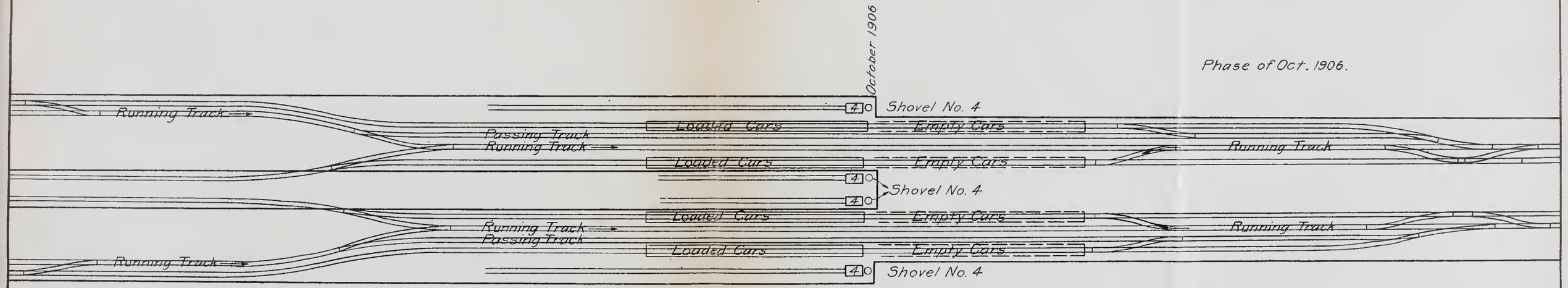

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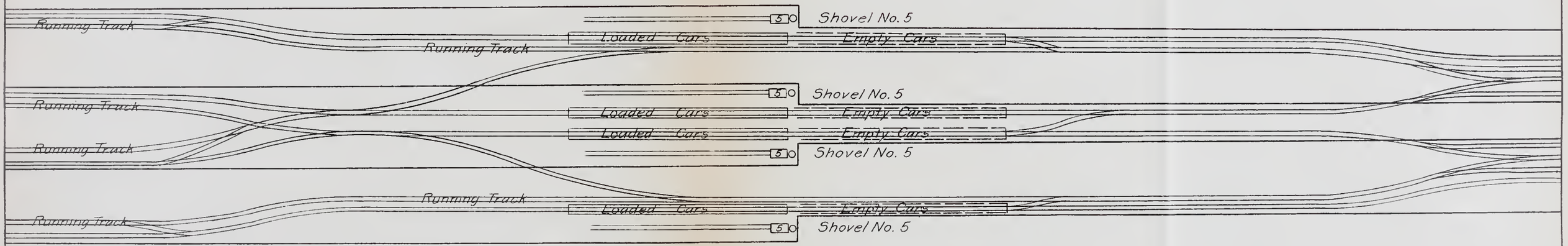
Diagram No. 7

DIAGRAM OF PROPOSED ARRANGEMENT OF TRACKS. PHASE NO. 5.

Phase of Feb. 1907.



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STATEMENT OF MR. JOHN F. WALLACE, NOVEMBER 3, 1905.

The CHAIRMAN. Mr. Wallace, the papers which you have sent to the Board by mail, consisting of notes on various subjects connected with the canal, received yesterday, have been read before the Board this morning, and those notes which you have made are now in possession of the Board, so that if you have any additional notes it would probably be well to have those read now.

Mr. WALLACE. I should like to say, Mr. Chairman, not as an apology, for I do not think an engineer ever ought to apologize, but as an explanation, that three days was a short time within which to prepare this matter. Some of the notes were culled from other matter, and you doubtless notice that there are a number of repetitions. That is, I mean that sometimes the same thing appears in two papers, only stated in a different way. Those that were sent to you I had no time to even read over before they were mailed. So, I have prepared an additional set, bound together, to check those previously sent.

There were some explanations that I have prepared to go with this that I did not have time to formulate; but it is a question in my mind whether that had not better be brought out by the questions that will undoubtedly suggest themselves. I can touch on them now, or I can wait until that is developed in the examination, as you see fit.

The CHAIRMAN. If they are concrete and they relate to the particular specific things, perhaps it would be better for you to read them.

Mr. WALLACE. I judge that what you wanted specifically or more particularly than anything else, was data that would enable you to determine the units of cost and time.

The CHAIRMAN. That was my understanding.

Mr. WALLACE. Here are some diagrams, one of which was sent with the report that I had prepared because it was easier to talk from than to attempt to describe in words, and I had a few extra copies prepared. (See diagram opposite p. 367.)

What I wanted to specifically illustrate by this was the method of carrying on the excavation work by steam shovels and trains. The particular thing to which I wanted to call attention was that the maximum depth, even for a sea-level canal, could be attained with a great deal less excavation than the entire section would call for, and the section could afterwards be removed, as might be desired. For instance, take even this hypothetic section of 100 feet base, on a depth of cuttings of 200 feet 70 per cent of the 200-foot bottom width section would be taken out, leaving 30 per cent. On that part of the excavation that would be 150 feet deep, on the 200-foot bottom width section, 68 per cent—that is, leaving 100 feet bottom width 40 feet below sea level, although even that could be narrowed—and so on down to 100 feet, where we have 64 per cent remaining.

The reason I wanted to specifically call your attention to this was to answer a suggested criticism that was made of the original estimate by General Hains, and that was in regard to the extraordinary width of berm—that it depended upon whether the slope was flat or whether the slope was steep or whether an ordinary retaining wall was used. The question of the treatment of the wetted slope and the question of the treatment of the dry slope is a matter that is almost impossible of determination in advance of sinking the central section to the ultimate grade, because it depends not only on the character of the material but it depends upon the sequence of the character of the material. By cutting down with a series of terraces and sinking the central portion of the canal portion to the maximum depth as soon as possible, leaving the widening to

be done afterwards, you can then make any particular form of section that the character of the material requires, and do it economically. For instance, if the material will stand well on the bottom of this section, the last three steps could be cut out and the slope of 1 to 1 formed; or, if it was necessary to put in a retaining wall, that could be constructed at whatever point it might be desired to construct it, leaving the width of the berm and the slope from the land side of the berm to the top to be finished off in whatever way should be necessary, according to whatever slopes or dimensions the character of the stuff that the cutting down at this point would develop.

The basic principles that regulate these steps are these: The more terraces there are, of course the more steam shovels can work simultaneously, because each one is supposed to preserve its integrity until it runs out at each end of the cut, and can be operated independently, although the excavation of each step will have to follow one after another in regular order; but the minimum dimension of horizontal width should admit of the maintenance of at least two railroad tracks; so that makes it practically 25 feet, which is shown here.

The rise should be the maximum one that will be safe as a base to work a steam shovel against, so there will be no danger of the material coming down in such a way as to injure the shovel, and in order that the relation between rise and tread, as if it were a staircase, will be properly maintained so as to preserve the average slope. As noticed, the resulting line of these terraces approximates about a 1 to 1 slope, although the intermediate slopes are 4 on 1, which is practically the slope that the material in the central 5 or 6 miles will stand to; that is, provided the elevation is not too high. There may be places in it where this slope will have to be modified, but the object of this diagram is to show the flexibility with which the excavation can be handled. Whether a retaining wall is used, or a 1 to 1 slope covered with a concrete jacket or apron, or a flatter slope is made; whether the berm is 50 or 75 feet wide, or the slope of the excavation is 1 to 1 or ¼ to 1 or ½ to 1, as the local conditions may require, that is a matter that will all work out naturally and with the utmost economy when the condition of the work is arrived at and it is necessary to determine that question, which should only be after some part of the central excavation is sunk to the maximum grade to which it is intended to construct the work.

Mr. NOBLE. This is parallel to the axis of the canal?

Mr. WALLACE. Yes.

You will note that the papers I have submitted to you only apply to the 5 or 8 miles of central excavation, for the reason that in whatever time the central excavation can be excavated, all other work of whatever nature should certainly be accomplished, the central excavation being the crux of the entire work. There are parts of the work, say between Bohio and Obispo, or possibly for some distance above Obispo, where the material may be taken out sidewise. It may be taken out by various methods, but in the central 8 miles it was the opinion of the writer that this material would have to be moved longitudinally out of the cut.

When you were there you saw, of course, a heterogeneous mass of dumps and tracks. I want to say to you that those dumps were dumps which were formerly used by the French company. The tracks were simply those that were formerly used by the French company. While I had mentally a general plan worked out, and was continually endeavoring to improve it, I did not desire to formulate it in writing until the last possible moment. The only thing we could do with the material and labor that was furnished to us was simply to patch up the tracks we found with the material we found there; and all of our work, with the single exception of American steam shovels, was carried on with the material found on the ground, the idea being that with my experience in this country and knowledge of conditions here and what could be done with American machinery, if I could only find what it would cost to do the work with the crude imperfect appliances on hand, I would be able to deduce reasonable cost from those data, imperfect as those data were. At least it was something. I satisfied my mind that I could certainly do better with American machinery and American engines than I could with the engines there, and better with the American rails than with the old rails, and better with American cars than I could with the cars that were there or by rebuilding those cars; so it was at least something to stand on.

I have details with me further than those submitted that I thought could be brought out as

questions were asked. One of them is the actual number of yards of material moved by each separate machine, whether it was a French excavator or an American steam shovel, and the average cost of doing the work with that particular machine. I do not know whether you have those data or not.

The CHAIRMAN. They have not been submitted to the Board, but I think they are available in the office here.

The SECRETARY. Yes, sir; I have them.

Mr. WALLACE. There was another point I had in mind in these experiments and that was this: Before throwing away a French excavator I wanted to demonstrate by actual practice whether that machine was efficient or not. It was the same way with the cars. I also wanted to be in a position so that if an American method was used where a French one had been used, or American machinery where the machinery we had on hand was used, I could have some definite unit of measure by which to determine whether or not it was the economical thing to make the substitution.

You can readily see the position we were in. We had an immense amount of machinery, and I did not feel that we would be justified in throwing that machinery away until we had demonstrated by actual practice that American machinery was more economical in service; but as a matter of course I would like to call your attention to the fact that there was one particular French excavator, No. 50, I think is was—these excavators were of different types—with which we loaded 160,000 cubic yards of material at an average cost of 4.8 cents per cubic yard.

Mr. HUNTER. What was that type?

Mr. WALLACE. It was one of the continuous-chain bucket excavators.

Mr. HUNTER. A dredger?

Mr. WALLACE. Yes; on the side.

Mr. RANDOLPH. Was that figure per cubic yard?

Mr. WALLACE. It was 0.0487; I left off the last fraction. It makes about 4.9 cents. It is just a trifle under 5 cents a yard.

Mr. HUNTER. You say 5 cents, and the item in your estimate of cost for excavation by steam shovel is 7 cents?

Mr. WALLACE. Yes, sir; but that steam shovel excavation at 7 cents of course included rock, and was to be an average for the entire work. The low cost of excavator 50, or 52, was due, of course, to our selecting a place where it could work in suitable material. It worked in the shaly formations, which we had to blast. It did not work in the basaltic rock or in the slate rock. The 7 cents that I have placed on the American steam shovel as what I consider the average cost of the work is intended to cover the entire work of the average of all classes of material.

The CHAIRMAN. Have you any questions, gentlemen?

Mr. HUNTER. There is one point I would like to have a little further information on, Mr. Chairman, if Mr. Wallace can give it to us at once. In the paper which was read this morning—the last paper in order as it came to us——

The CHAIRMAN. No. 8.

Mr. HUNTER. It is the general plan as to maintenance of construction, unit costs, and time—you said, Mr. Wallace, that there were now 10 new American shovels on the ground.

Mr. WALLACE. That is a supposition on my part.

Mr. HUNTER. That is to the point, however, about which I am going to ask you. It does not matter whether it is 10 or whether it is more. The next step in your computation is that you consider that 24 additional shovels may be installed per annum.

Mr. WALLACE. Yes, sir.

Mr. HUNTER. May I ask how you fix that number at 24?

Mr. WALLACE. It is simply a mere matter of judgment. Of course in installation I calculated that they could place more. For instance, if 2 shovels were sent and regularly installed each month throughout the entire year, of course the average for the year would be half the annual average of a shovel; but the shovels will do more than that, for the reason that January, February, March, and April are comparatively dry months, and there are more dry months in

the first part of the year than there are in the last. I calculated roughly that the shovels would be installed at a faster rate in those months; in other words, that more than 12 of them would be at work before the 1st of July and less than 12 after that. Now, it may be possible up to a certain point to install a shovel once a week, you understand; but the reason I fixed on 24 was that after a careful study I desired to state a number that could reasonably be installed without strain and without doubt during the year. that was all.

Mr. RANDOLPH. The number that you could provide tracks for?

Mr. WALLACE. Yes; there are tracks to be provided, and the organization and everything that goes with it. I thought that while we might do better than that, at least 24 should be installed each year.

Mr. HUNTER. Yes; at least. You would not consider that 24 steam shovels in a year are all that you can reasonably expect, with the whole of the United States to draw upon? You can get as many steam shovels, I suppose, as you want?

Mr. WALLACE. You can get as many steam shovels as you want; yes.

Mr. HUNTER. Then the question is whether, having practically an unlimited supply of steam shovels available, it will be impossible to provide track accommodations for only 2 additional steam shovels a month.

Mr. WALLACE. That was not the point. I did not intend to put that as a maximum. I intended to put it at a number that no one could question. In other words, I intended to make it a minimum.

Mr. HUNTER. You will see the difficulty I have in my mind. You assume 24 shovels a year and that the supply, the additional installation, will proceed at that rate until you have reached a maximum of 82 steam shovels in that long cut. That is what I gathered from what the Secretary read to us this morning. I contrasted that with your report published earlier this year in which you suggested that there may be 144 shovels.

Mr. WALLACE. I beg your pardon. That 100 shovels was intended to apply to the entire distance through the central excavation, which, for a sea-level canal is 20 miles long, and this paper is only stating what I thought could be installed in the central 5 miles.

Mr. HUNTER. I beg your pardon. That part I did not gather. That is the difference. Your report applies practically to the 8 or 9 miles covered by the whole divide.

Mr. WALLACE. The report applies to all of this distance in which steam shovels are to be worked, but this paper now only applies to taking out 100,000,000 yards, approximately, from the central 5 miles. I did not make that clear in the paper because, as I understood it, when I was here last week, the problem which you put to me was the disposal of 100,000,000 yards of material from the center of the excavation. Now, during the time that you are installing these 24 shovels a year and getting out the amount according to this schedule, I would expect that other shovels would be installed or other methods of excavation would be installed and the entire work would go on in proper sequence.

Mr. HUNTER. That is to say, other installations will take place at either end of this 5 miles?

Mr. WALLACE. Certainly. This being simply the crux of the work and being the section the progress of which would regulate the completion of the canal, I presumed that was what you desired me to treat of.

Mr. HUNTER. But that was the point that was not clear. The paper has only been read to us once and we have had no time to interpolate questions. I understood that the paper on the progress of the work applied to the whole of the work.

Mr. WALLACE. No, sir; this computation in regard to what work could be done was only intended to apply to the central 5 miles. Of course the supposition was, as I understood it from Mr. Dose's figures, that there would be 100,000,000 yards in 8 miles, but for safety in this computation that was supposed to be concentrated in the 5 miles.

Mr. HUNTER. That makes the matter much more clear. Then the only question remains as to the practicability or not of installing a greater number than 24 shovels per annum during the first three or four years in that 5 miles. If it relates to the 5 miles, possibly it is a safe figure to take, but it is a minimum, I understand from you.

Mr. WALLACE. I only intend it to be a minimum figure, and my thought in these figures I submitted to you was all along the lines of an endeavor to be on the conservative side.

Mr. RANDOLPH. You estimate 3 miles of track for every shovel, do you not, Mr. Wallace?

Mr. WALLACE. Approximately, yes. That includes main tracks, storage tracks, dump tracks, and everything in the nature of a railroad track that is dependent upon the number of units that are at work.

Mr. HUNTER. There is one other question, Mr. Chairman, that I would like to put to Mr. Wallace. It is in respect to your estimate of the cost of material, which, after adding 10 per cent, you suggest is 60 cents all around. Have you considered or can you give any figures that you have estimated for the cost of pumping per cubic yard of the cutting, supposing a sea-level canal is going to be constructed? We are considering two projects, a sea-level project and a lock-canal project. In the sea-level project, have you formed any estimate of what the additional cost will be per yard for pumping? That is not included, as I understand from your figures.

Mr. WALLACE. No, sir. I left that out for two reasons. First, it was utterly impossible to make any computation of that kind, that is, except in a most general way, and I thought my other figures were large enough to absorb any reasonable amount of that. Again, something I have not referred to in those papers, if I were doing that work myself, as an engineer in charge of the work or as a contractor, I would consider as a possible plan the excavation in the dry to 40 feet below sea level of one central ditch or channel, simply wide enough to admit of the passage of my dredges and vessels, and I would do the rest of my widening—that is, below sea level—in the water.

Mr. HUNTER. Would you not encounter, by proceeding with the work in that manner, a difficulty which must be met in days to come, when the canal prism will be widened, in the way of protective works where you are working under water? That is the great difficulty we always experience when we are blasting rock under water, particularly in a case of this sort, when, as you said yourself, the material is very mixed in its character. Some parts of it may have to be protected, some may not have to be protected, probably only a very small proportion of the cut may have to be protected; but how would you proceed with that protective work if you complete a section of the cut under water?

Mr. WALLACE. That is one of the difficulties; so, of course, doing it under water is an alternate plan that is to be determined. In my mind I thought the determination of that question should be left until we reached that point in the actual progress of the work. Now, there are places there where, if it were necessary to treat in some special manner, it might be necessary to cofferdam off that particular part in order to put in a retaining wall or in order to treat the slope.

Mr. HUNTER. That would be a very serious matter, to cofferdam to the rock foundation, with a head of water of 40 feet.

Mr. WALLACE. The probabilities are you would not have to construct your wall the entire depth of 40 feet. It would depend entirely on circumstances.

Mr. HUNTER. You might not have to, or, on the other hand, you might have to protect the lower part of the side of your cutting and not the upper part.

Mr. WALLACE. I do not think it would be probable that you would have to go to the full 40 feet below sea level before you would determine that question, and if you did not have to go to that depth, then you could cofferdam off. You might only have 10 feet of water to cofferdam in and you might have 20. On work with which I have been connected I have seen cofferdams put in the Mississippi River in a current of 5 or 6 miles an hour, on the Rock Island Rapids, in 20 or 25 feet of water, and done cheaply. With the proper appliances it is not a very difficult thing to do. Your area would be very small, because in that case you would take your whole canal section and build your dams right across the canal. I do not imagine there would be a case where you would want to do that after you had excavated your full 40-foot channel. I think before you got down to that depth you would have a comparatively moderate depth through which to sink your test pits or take your borings; that you would be able to determine accurately the character of your material before you would excavate that part, and could arrange for it by other means. That is, I mean you could build your cofferdams before you go down there, or you could let

earth barriers remain that would answer the same purpose, and then pump out the intermediate spaces. As far as the excavating of rock under water is concerned, there is one process that has not been touched upon in any of these reports, but I think Mr. Bunau-Varilla referred to it, and that was the breaking up of the rock by what is called "chisel work."

Mr. HUNTER. You mean the Lobnitz system?

Mr. WALLACE. I do not know what you call it.

Mr. HUNTER. You, perhaps, need not enlarge upon that. We have discussed that at great length here. It is a process with which Mr. Quellennec and I both happen to be extremely familiar.

Mr. WALLACE. I simply wanted to remark that I worked that same system for five years over thirty years ago in the Mississippi River, with the hardest possible limestone rock, and we did it with slender chisels, probably 16 to 18 feet long, and weighing only a few tons. Still we had remarkable success with it. I only wanted to touch upon it as a possibility.

Mr. HUNTER. I am doing it in quite another part of the world on a very large scale, and we have had that very much before us. Do you not think it would be a little more prudent, in contemplating the construction of a great canal of this character, for this Board to regard that the whole of this excavation in the Culebra cut may be removed in the dry?

Mr. WALLACE. I think it would be more prudent; yes.

Mr. HUNTER. And below whatever elevation may be necessary to allow some safe and conservative condition?

Mr. WALLACE. I think it would, Mr. Hunter.

Mr. HUNTER. What do you think that elevation would be?

Mr. WALLACE. Down to 10 feet above sea level the cut should drain itself by gravity. What it would cost per cubic yard to pump the water from the excavation below that elevation I do not know.

Mr. HUNTER. How are we to find out? What is your view about it?

Mr. WALLACE. I will give you some experience that may help as data. I have seen pumped out a cofferdam containing about 10 acres of surface—I have not figured this out, because I did not expect to raise this question—with an average depth of 10 feet, in twenty-four hours. This was over twenty-five or thirty years ago, and the only factor that I do not bear in mind now was the number of centrifugal pumps we used and their size.

The CHAIRMAN. Do you remember the cost?

Mr. WALLACE. I do not think the cost exceeded $100 for that area. That is just simply a rough estimate, but I do not remember the size of the pumps nor how many we had. I know we had our pumps all at the lower end of the dam.

The CHAIRMAN. You had the pumps on hand? You did not have to buy them?

Mr. WALLACE. We had the pumps on hand; yes. I mean $100 was simply the cost of the coal and the wages.

Of course the cost at Culebra would depend on the way the cut was drained—on the watershed that would be tributary to your cut when you got down to the greatest depth, and also on the amount of rainfall, and on a great many elements that are very difficult to determine. Of course the probabilities are that anyone doing that work would do everything possible to crowd it during the drier months.

The CHAIRMAN. Have you thought of a level at which you would almost certainly have to pump?

Mr. WALLACE. I should judge that that cut could be properly drained down to about, possibly, 10 feet above sea level.

Mr. WELCKER. Mr. Chairman, the Committee on Unit Prices has adopted the figure of 45 cents per cubic yard, but it is a matter of great uncertainty. We have put that figure on it because it was necessary to do so; but no man in the world knows how much it will cost.

Mr. HUNTER. I was very anxious to get Mr. Wallace's opinion upon that. The Committee on Unit Prices put it at 45 cents.

The CHAIRMAN. With the material on the top of Culebra, red clay and chocolate-colored clay, is it practicable to make an effective drainage of that area and save removal, or would you think it would have to be stripped?

Mr. WALLACE. My own view is that it should be stripped back to the extreme edge of the cut, wherever the 1 to 1 slope took it, regardless of whether it left a wide berm; and it would be practicable to leave a berm on the top material that would not slope on the clay. If you gentlemen will remember, on the east side of the north end of the cut is quite a wide berm, and it was my policy to keep a berm of that character always far enough back so that there was no danger of the clay coming down into the cut, and then endeavor to drain the bottom of the clay slope. Of course, on the south side of the slope the blanket of clay runs down into the valley of the Rio Grande at a much lower elevation than it does on the north side, and it might be necessary to take some steps to drain it, but I should think it would be preferable to remove it as far as possible.

There is another point, however. If that material is removed in a dry season it can be removed very economically. That is, the elements of expense that are attached to it in a wet season do not attach to it in a dry season. There are some springs in it that of course could be drained, but the removal of the material in, say, December, January, February, and March, or rather January, February, and March particularly, is an entirely different proposition from what it is to remove it at this time. The only reason why it should be removed now is because it was not removed then. But the policy which I had adopted, if we could have been able to get our machinery and apparatus installed, was to remove sufficient of that clay during each dry season so that it would not have to be touched during the wet season, and confine our work to the shale and rock during the wet season. If the work is organized along those lines, 75 per cent of the trouble of the dump is eliminated.

The CHAIRMAN. I infer from your notes on the subject that you do not think any rectification of the alignment through Culebra is likely to be found advantageous.

Mr. WALLACE. It may be possible to make some trivial change, but I do not think it would be practicable, for any moderate cost, to make any radical changes of alignment. Mr. Ruggles, the engineer who actually made the surveys, had a map prepared upon which estimates were based. Cross sections were made of that entire territory, and when I left Panama they were in the chief engineer's office. They are a series of comparative estimates showing what could be done in change of alignment. It seems to me that if we had any money to spend we had better spend it in widening our canal section rather than endeavoring to radically change the alignment. That is the conclusion I came to from a study of the subject.

Mr. STEARNS. There was one question asked about the moving clay on top, and I will go on with the same subject. While we were there, there was a slide coming into the cut on the Pacific side of the highest hill at Culebra, a few hundred feet beyond. That was starting, I should say, about 1,000 feet from the center line of the cut. Could that be drained, do you think?

Mr. WALLACE. It might possibly be drained; but the trouble about the slide there now is that during the wet season nothing should be removed from the toe of the clay. Whenever you take away anything from the foot of the slope—that is, remove the toe of a clay slope in a wet season—the slide is inevitable; and with the exception, I presume, of one or two men, I doubt whether there is anyone on that work now who had any position of responsibility connected with it during the dry season. Consequently, their point of view is more pessimistic than a person's who has handled that same material in a dry season. The proper way to handle that clay, to my mind, is to go back far enough at the top and work it off and take the weight off of the sides of the excavation. There is a distance you can go back, and there is a possibility of drainage there that I should judge would enable the work to be carried on to such an extent during the dry season that the clay would be a minor trouble in the wet season.

Now, the drainage, for instance. If you go back far enough, of course, you can drain it by a system of tunnels or by a system of deep open cuts with proper slope, properly protected. There are various ways of doing this, but it would have to be decided by whoever was responsible for the work from an actual study of the situation right on the ground.

There is one remark I should like to make about slides. A slide with 50,000 or 100,000 cubic yards of material in it looks like an enormous one, but when you consider the proportion of that slide to the entire work in the excavation, it is simply a minor detail.

Mr. STEARNS. I did not get any expression of opinion when on the ground as to the slide, except that my informants thought it had to come out, as it was already moving; and as I understood this case, they were not cutting into the foot of the clay where the slide occurred except as it came into the canal section over the edge of the rock and was obstructing the tracks in the canal section.

Mr. WALLACE. That particular slide, I think, could be helped by drainage. There is practically a spring or vein of water that comes down there. You understand how those slides work. It is necessary to understand what is underneath them. The basaltic rock is on a very steep inclination toward the Pacific, and then there are places in the rock where there seem to have been ravines. The clay would fill up these ravines and would follow the ravines down into the excavation. We had a slide there that came down one of those small ravines last winter, if you recollect, Mr. Chairman, and I do not think there was over 15,000 or 20,000 yards of it, but it stopped our work absolutely at the time. That was about a year ago; but it was due to the fact that the tracks lapped each other and the excavator on one track was south of the slide, and on the other track north. All trains had to pass the point, and the slide came down and cut off access to the excavation in both directions; but that was due to the old arrangement of the tracks. They had not been changed up to that time. That was about a year ago now, if I remember correctly, in September, 1904.

The CHAIRMAN. Yes; I remember it. It occurred also, I think, at a point where the stratification changed. There was a radical difference in the material just on that dividing line.

Mr. STEARNS. My question was whether such slides could be stopped or whether they would continue to slide and have to be taken care of.

Mr. WALLACE. The question of slides is one that should be of less importance every year that the work goes on, if the material is properly handled in the dry season.

Mr. STEARNS. You would advise taking it off for a certain distance back on the rock?

Mr. WALLACE. Yes.

Mr. STEARNS. In the dry season, as I understand?

Mr. WALLACE. Yes.

Mr. STEARNS. Will that stop it, or would it also need drainage?

Mr. WALLACE. That depends altogether on the conditions that would be developed at each point. Of course the cause of these slides is the fact that clay, a soft material, is lying imposed on an inclined surface of hard material. The clay becomes saturated, and the surface of this hard material becomes lubricated by the saturation, and the weight of the saturated material, of course, helps to assist in the movement. Now, where you have that at a point where there is anything in the nature of a ravine or a depression in the original foundation, and water is following it similar to a subterranean or submerged stream of water, the case is still further aggravated. At this particular point where the slide occurred there has always existed a spring. If that spring and stream of water can be cut off, of course you remove one of the difficulties.

Mr. STEARNS. My question is whether you thought it could be.

Mr. WALLACE. Yes; I think it could.

Mr. RANDOLPH. There is a spring at the head of that slide, and the French company had three tanks there. They seemed to have used it as a water supply.

Mr. WALLACE. It goes without saying that the farther away from the point of the slide you can take and divert the water the better, of course.

Mr. WELCKER. Mr. Wallace, in one of your papers that has been read this morning you say that the condition of the sea bottom at La Boca is just the same as in Limon Bay, if I understood it correctly.

Mr. WALLACE. Not exactly the same, but I said there were places where the same conditions occurred. That is, there are places where there are large masses of mud at both localities.

Mr. WELCKER. That is a factor of great importance in relation to the dredging that would

have to be done in Panama Bay. Is it your opinion that the bottom of the sea of Panama Bay, consisting of mud, is in the same condition as in Limon Bay?

Mr. WALLACE. No; I do not think it follows as far out in the bay. It goes only a short distance out from La Boca, from the shore line. The reason is that there is a much larger watershed bringing down silt-bearing waters tributary to Limon Bay than to Panama Bay, owing to the greater watershed of the Chagres as compared with the watershed of the Rio Grande.

Mr. WELCKER. And you also state that there will be less mud in the region of Ancon-Sosa than there would be in the present channel of the canal?

Mr. WALLACE. I should think there would be less mud there.

Mr. WELCKER. And not of so great consistency?

Mr. WALLACE. Yes. That, of course, is only supposition upon my part. I submit it for your consideration.

Mr. STEARNS. I would like to ask Mr. Wallace if in that same locality he has made borings where the ground is above high tide; that is, in the vicinity of La Boca pier?

Mr. WALLACE. No, sir. The necessity for borings there was not the same as in Limon Bay, at Colon. At that latter point our harbor facilities were restricted and we were considering the location of the mouth of the canal through it. The depth was moderate. We wanted to know, naturally, what we had to contend with below, and the soundings in Limon Bay were taken very extensively. As we had practically already an open channel out to the sea at Panama, the same necessity did not arise for taking soundings at that particular time at that place.

Mr. STEARNS. My question related to borings on the land above high-water line.

Mr. WALLACE. No; we did not take any at La Boca.

Mr. Chairman, there is one thing in the testimony of one of the other engineers which I would like to correct. That was in regard to the price of coal. The price of coal, according to my recollection, was $5.50. I think in these cost sheets you have it was still carried in at $7.50. That occurred in this way: When I took charge, a year ago, the price was $9.50 per ton for coal delivered at Culebra. We finally were able to get the Panama Railroad Company to reduce it to $7.50. Then it remained at $7.50 for quite a period, and we afterwards got it down to $5.50. It took so long at the end of the month to get the accounts around that the clerks who made up these monthly cost sheets would find out the price of coal and, knowing the amount used, would anticipate the cost and close up their cost sheets. Those men were perhaps not informed of the reduction of the price to $5.50, and evidently continued to carry the coal in these cost sheets at $7.50 a ton.

The CHAIRMAN. I saw that, and I noticed the inaccuracy. I was sure it was a mistake.

Mr. RIPLEY. Mr. Chairman, the explanation given of that was that $7.50 was the price of the coal at the engine or boiler at which it was used.

The CHAIRMAN. Yes; put on the engine.

Mr. WALLACE. I think that was simply a piece of guesswork, because that element was never kept track of as a distinct item when I was down there except in this way: That expense, if it was put on the engine, was charged to the transportation expense. If it was put on a steam shovel, it was charged to the expense of excavating. I mean the labor did not go into the price of the coal, nothing except the amounts paid the Panama Railroad Company after the coal was delivered on a side track at Culebra; but the expense of handling the coal was dependent on where the labor was charged that handled it. It was either absorbed in transportation, mining, excavation, track work, or in general expense. I mean general expense around the quarters.

Mr. RANDOLPH. In the cook house?

Mr. WALLACE. Yes. That was in Mr. Dose's examination. He came into that work, I think, along in the spring, and he was so occupied with his other duties and the clerks had been trained in making up these cost sheets so thoroughly that I do not think he was entirely familiar with the details of the way those cost sheets were made up. I happened to be, because when I started this system of cost sheets I had no one there who was familiar with it or had ever used it, so the result was I had to go into details until I trained the clerks so they were able to do it.

Mr. STEARNS. Mr. Chairman, Mr. Wallace in his article did not give us any detail or statement, I think—I may be mistaken in this—as to the treatment of the Chagres River during the construction of the canal from Bohio up to Obispo, as to how the water is to be taken care of during construction. I would be obliged if you would enlighten us on that point, Mr. Wallace.

Mr. WALLACE. The solution of that question I consider would be simplified by the immediate construction of the Gamboa dam, which would leave only the regulated flow of the Chagres to contend with, instead of the flood waters.

Mr. STEARNS. And what provision would be made for the regulated flow?

Mr. WALLACE. The diversion channels. I mean on the sea-level plan. Of course the diversion channels should be constructed immediately and they would take care of the regulated flow.

Mr. RANDOLPH. How long did you figure it would take to build that dam?

Mr. WALLACE. Of course that depends on the time at which the dam is authorized. If the engineers on the ground could know by, say, the 1st of next April or even the 1st of July that that dam would be constructed, it should be completed in two dry seasons afterwards. That is, if they are able to get the necessary material on the ground for use during the first dry season at the commencement of that dry season, and have the organization and everything all ready for it, then I should judge it would take about two dry seasons from that time to complete it. It might take three.

Mr. RANDOLPH. That is the dam that goes to elevation 200, is it?

Mr. WALLACE. Yes. Of course the bulk of that dam is inside of what might be called the center of gravity of haul from the Culebra cut; and one of the methods I had in view was the construction of a railroad from Culebra to that dam in order to deliver the material there. While it would probably cost something more per cubic yard to deliver the material at that point over and above what it would cost to waste it in the cheapest way, still it would make the filling comparatively inexpensive.

Mr. STEARNS. Could the diversion channels be built in the same time, sufficient to take the regulated flow?

Mr. WALLACE. Yes.

Mr. STEARNS. And also the diversion channels on the other side of the canal, to take the small streams that come in?

Mr. WALLACE. I do not see why they could not be.

Mr. STEARNS. Have you made figures as to the number of cubic yards to be removed for those diversion channels?

Mr. WALLACE. No, sir. The reason that was not done was this: During my administration there as chief engineer the work was taking up all the time, and all the men we had were occupied in doing work that was absolutely essential. The question of whether we needed diversion channels or not, or when and how they would be located, could not be determined until it was ascertained whether the canal would be at sea level or with multilocks or intermediate lakes, and I did not think it was advisable to neglect work that was pressing to make comparative estimates of that nature then, as the amount was small and the matter a minor consideration at that time as a whole.

Mr. HUNTER. Mr. Chairman, has Mr. Wallace seen the plans we brought back from Panama in which those diversions were shown in detail?

The CHAIRMAN. Mr. Wallace saw that map when it was on the Isthmus; I think I have talked with him about it; but this plan, Mr. Wallace, shows the line of the canal on a scale of about 1 in 5,000, and on its margins are shown various diversions. You recollect that?

Mr. WALLACE. Yes.

Mr. STEARNS. I would like to ask Mr. Wallace if he has ever looked at those channels to ascertain whether they appeared to have sufficient capacity to take the regulated flow?

Mr. WALLACE. No; except in this general way: It may be unscientific to say it, but those of us who have been engaged in active practice for years, after a while, when we look at matters generally and go over territory in the field and look at plans, can form a very close idea of whether a general scheme is practicable or not without going into detailed calculations.

Mr. STEARNS. I did not ask for the details, but whether you had formed any idea as to whether they were sufficient.

Mr. WALLACE. I formed the idea that they would be sufficient, or, rather, could be made so at moderate cost.

Mr. RIPLEY. As I understand it, Mr. Chairman, in the excavation of the Culebra cut the intention is to take the excavated material out at either end of the cut, some of it toward Obispo and some of it the other way.

Mr. WALLACE. Of course I do not know what the scheme is now, but my intention was to provide four avenues for handling the material. One would be parallel to the Panama Railroad, using it as a base. Another would be the double-track system down toward the Gamboa dam, taking whatever material was necessary there. The other two were southward, toward the Pacific. My general idea was that the bulk of the material in this heavy central section of 5 or 8 miles should go toward the Pacific, for the reason that we had the minimum rainfall there, and our spoil banks were nearer the cut and we would have less haul, although the question of haul, after material is on the cars on through tracks and on trains moving, is a very small item. Two cents a cubic yard would haul the material 10 miles after it is once in motion on trains.

Mr. RIPLEY. I had in mind the difficulty that would be met at the end toward Obispo. The Chagres River at Obispo is about 45 feet above sea level.

Mr. WALLACE. Yes.

Mr. RIPLEY. And it also rises about 20 feet, as I understand it, during the flood stage, so that would make it about 65 feet. You would have to have a dam there at least 10 feet higher to keep the water from going into the excavation.

Mr. WALLACE. Long before you got to that point you would have the Gamboa dam and the diversion channels, and only have the regulated flow of the Chagres to take care of and the facilities for doing it. The bulk of the material—that is, every cubic yard of the material that could be disposed of toward the Pacific slope—would go that way, and there would only be taken toward the Caribbean slope such material as might be used for some specific purpose, for filling or for the Gamboa dam, or there might be low places along the railroad where it could be disposed of economically—that is, the material that comes out of that end. The excavation for quite a number of miles, if a sea-level canal is constructed, between Bohio and Gamboa, or possibly farther south, could be disposed of on the side.

The CHAIRMAN. There is a dumping ground?

Mr. WALLACE. Yes; a dumping ground at places. The matter was quite carefully gone into in connection with one of the firms that constructs conveyors. It was calculated that the material could be excavated—that is, soft rock or the shales—from 50 to 100 feet in depth and conveyed about 1,500 feet sidewise for a trifle less than 35 cents a cubic yard.

The CHAIRMAN. With a cantilever?

Mr. WALLACE. With a series of belts or conveyor machines.

The CHAIRMAN. What do you think of the availability of the material in the Culebra cut to be used in connection with a partial earth dam—a core wall, reenforced by that material?

Mr. WALLACE. I do not see why it could not be used.

In connection with the utilization of the material out of the cut, I desire to say it was the plan to install modern rock-crushing plants at each end of the cut and crush this basaltic rock and use it for track ballast, in the first place, and then take what we call the screenings for use as part of our concrete material, and also for road work and work of that character.

The CHAIRMAN. Do you think the material in the Chagres River available for concrete in large quantities?

Mr. WALLACE. It could be made so. The best material we found in the way of sand was the beach sand at Panama. The screenings from this trap rock make excellent concrete material. You could not have better.

Mr. GUÉRARD. What would be the cost of concrete at the Gamboa dam.

Mr. WALLACE. That depends altogether on the specification of the concrete. It would be

very difficult to answer. I should judge, offhand, that it would not be over $8 a yard and might run as low as $5.

Mr. GUÉRARD. Do you favor a dam at Gamboa entirely of masonry, or partly of masonry, using a core wall?

Mr. WALLACE. I feel rather delicate in expressing an opinion on dams before gentlemen who know so much more about them than I do; but, considering the fact that there is an unlimited amount of material available at Culebra that has to be disposed of at some place, from my point of view I would rather favor a composite dam; also, considering the fact that a masonry dam would necessarily have to be constructed of concrete. I do not think there is rock suitable on the Isthmus, to any great extent, for what is called cut-stone masonry; but that climate is extraordinarily suitable to concrete work. It has all the favorable conditions.

There is one point to which I desire to call the attention of the Board, Mr. Chairman, looking toward the safety of all these estimates. There is quite a field during this work for a great many economies. There is no reason why coal should not be delivered there for $4 or $4.50 a ton. There is no reason why cement ought not to be delivered there practically as cheap as or cheaper than it is at a great many points in this country; and the extraordinary amount of material to be handled and its ability to absorb even an expensive plant places it above any work that I have ever known of, particularly in America, as one that can be economically carried on. The work we do in this county, where there are 1,000,000 or 2,000,000 yards to move and where it is scattered, presents the same problem compared with the Panama Canal work as a factory which turns out 10 pairs of shoes a day by hand or by crude methods compared with one turning out 1,000 pairs an hour by the most improved machinery.

There are great possibilities for economies resulting in cost below the figures that have been submitted by me. These unit quantities are based on what I think can be actually accomplished, considering what has been done with inefficient appliances and poor labor as compared with what has been done in this country on a relatively small scale. I have had material moved that is somewhat similar to a large part of the material in the Culebra cut, except the basaltic rock, from 3 to 5 miles, in small quantities, as low as 29 cents a yard on an average.

Mr. GUÉRARD. How many yards of concrete could we make per day for the Gamboa dam, approximately?

Mr. WALLACE. An unlimited quantity could be made. I would not like, offhand, to place a limit on the amount that could be made, but I should judge that it would be possible, with machinery there, to make 8,000 to 10,000 yards a day.

Mr. GUÉRARD. Where would you get the rock?

Mr. WALLACE. Out of Culebra, or some other point there. I would crush it. The thing that to my mind would limit the amount of concrete that could be made at the Gamboa dam in a day would be the fact that you would probably want to put it in the dam in layers, and would not want to put in as high as 10,000 yards in any single day. You would want to put it in layers, a moderate amount at a time, and let the different layers set.

Mr. TINCAUZER. Mr. Wallace, do you suppose that all the materials are at the dam site, so that you can use them for putting into the dam, or would you expect also to transport the materials to the place during the working of the dam?

The CHAIRMAN. Would you accumulate the material or would you expect to bring it daily?

Mr. TINCAUZER. When you say 10,000 cubic yards of stone or cement or sand, do you mean they will be transported to the working place?

Mr. WALLACE. Of course that was simply a broad offhand statement. I do not presume you could keep up that rate of speed right along indefinitely. It would be a large amount of material.

Mr. HUNTER. Mr. Wallace, assume that there are 300,000 cubic yards of concrete in the core wall of the Gamboa dam, how long would it take to put that in?

Mr. WALLACE. As I said before, I should judge it would probably take about two years to finish it. If I were responsible for the work I would want about two years to do it.

In answer to Mr. Tincauzer's question about the accumulation of material, that would depend on the conditions right around the work. Part of the material you might want to accumulate;

part of it you might want to bring in at intervals. You would not want to depend on getting everything in the proper order and making the delivery every day. Of course the broken stone might possibly be manufactured right on the ground. You might find some place where you could dump your rock from the cut and store a large supply at the crusher. You might have a few days' or weeks' supply of broken stone on hand, and in addition a supply of rock to crush on hand; the main thing would be to get quantities enough in reserve so that an interruption of, say, twenty-four hours in any class of material would not delay the work.

Mr. TINCAUZER. The cement necessary to make 10,000 cubic yards for this dam is an enormous quantity. It would have to be brought in steamers from North America, and in order to make this great quantity it would be also necessary to bring by railway great quantities of cement, and the traffic on the railway must be the same as it is now. How many trains would be required to be interpolated for carrying the materials from Colon to Gamboa?

Mr. WALLACE. I could handle, on a double-track railroad between Colon and Obispo, twenty times the present traffic over that railroad without any difficulty whatever.

Mr. NOBLE. I think the amount of cement required for 10,000 yards of concrete would make about 40 or 50 carloads a day.

Mr. WALLACE. Yes; you would have no trouble in handling the cement. It would seem that would be the smallest part of the difficulty. The thing that would give the most concern would be keeping the rock crushed for that large quantity. It was our custom last summer to keep about a thirty-days' supply of cement on the Isthmus for our work, but of course the amount of cement was comparatively small. For a large work like the Gamboa dam a sixty days' supply should be stored there. It is rather dangerous to attempt to store cement in that particular locality longer than sixty days on account of the moisture, but I should think it could be safely handled for that length of time.

The CHAIRMAN. Would you regard that rock at the Obispo lock site as suitable for concrete?

Mr. WALLACE. I should think that rock would be suitable if it were properly crushed. It is not as good, of course, as the trap.

The CHAIRMAN. It is a conglomerate?

Mr. WALLACE. Yes; but in that conglomerate there is some stone that is very hard in quality.

The CHAIRMAN. Do you think that those gravel bars, taking the different grades and relying on the material as it is, pebbles large and small, and sand, with an admixture of cement only, would be a safe thing to use?

Mr. WALLACE. Some of the best concrete I ever saw was made of just such material as that. A little clay does not hurt. If it had not too much clay or too much dirt in it it makes a very good concrete with the proper quality and proper proportions of cement.

Mr. QUELLENNEC. I wish to ask Mr. Wallace if he has made any plan for the location of dumps where the spoils of Culebra are to be put?

Mr. WALLACE. Yes: in a general way. I noticed that in Mr. Stevens's examination he said that no study had been made of those dumps. The question has been taken up and reported upon. I do not know what is the matter with the records. They are quite voluminous in the Panama office, but I presume they are not available owing to the fact that there have been so many changes among the clerks that he has not found it yet.

Mr. QUELLENNEC. Have you any idea of the distance of transport for the spoils of Culebra?

Mr. WALLACE. I should judge that the average haul of that material would be from 10 to 12 miles, with 100,000,000 yards. That would cover, I should judge—you gentlemen can check me on this with a mental calculation as I go on—about 4 square miles of territory approximately 30 feet deep. With the material that can be handled on flat cars and unloaded with what we call a Lidgerwood unloader, and spread with power bank spreaders, in my opinion the most economical height of the dumps would be about 15 feet. The territory should be laid with long tracks and a large number of them, so the trains can run on these tracks perfectly straight. The material could be plowed off the cars. Then when the bank accumulates on the side it could be plowed off with the spreaders. When there is room for another track a new track could be constructed or the old one thrown over to the new edge of the dump, and in the meantime some other track

of a similar character could be used. In that way, with shale material, you will work over a material so fast that the settlement will not hinder the progress of the work, particularly if the material is homogeneous at all.

The trouble they have had with the dumps so far has been the fact that they have been too high. Clay would be put on a dump and within a few moments after the clay was deposited shales or basaltic rock would be dumped on it. You could not expect to keep up a dump handled in that way, and there were not a sufficient number of old dumps to take care of the amount being excavated at that time.

Then, again, a dump 30 or 40 feet high will settle more than simply the proportionate height, because of the weight of the superimposed material on the material below, and so on. If a track settles 2 or 3 feet, or a large amount of material sloughs out of the edge of a bank, a track may be destroyed entirely; but with a low dump, if settlement is 2 or 3 inches, the track is not injured enough to even cause a derailment.

Mr. QUELLENNEC. Can you say what would be the average weight of a train with new engines and equipment?

Mr. WALLACE. Taking the weight of cars and everything, engines should be provided that would haul from Culebra to the sea trains of at least 1,000 gross tons. The capacity of a steam shovel depends almost entirely, inside of practical limits, on always having a car there ready to dump the material into, and 5-yard dipper steam shovels, for a short time, have shown a continuous working capacity of 4,500 to 5,000 cubic yards in ten hours; that is, if the cars could have been kept there for those shovels to fill.

To digress a little, one reason why I have suggested this increased size of terraces over and above what was used by the French company is this: After a steam shovel cuts beyond the reach of a dipper of material, it stops five or ten minutes to move up to a new face, and if the number of those moves can be reduced by having a high face and a wide face of course you gain that much, as long as the width or depth of the face is not beyond the reach of the steam shovel. If you have an eight-hour day and four-hour shifts, and place at one of these shovels, for instance, 20 flat cars that will hold 20 cubic yards apiece, you have 400 yards on 20 of them. It is a question what that material would weigh, but say it would be from 400 to 500 tons. If you take 25 of those cars you have 500 yards on the train. The size of the trains should be so regulated that the switching movements should, if possible, come at the break in the four-hour shifts. The cars should be continuously supplied to the shovels, and if the shovels can load 1,000 yards or 800 yards in four hours, the train lengths should be either adjusted to that capacity or the number of trains should be some multiple of it. There should be two trains in that time, or some regular number of trains, and then the switching should be done prior to the commencement of the work, during the two hours at noon, or at the end of the work. There should always be sent ahead of the shovels sufficient surplus of cars so that the only movement of the cars required would be to work them up to the dipper. Under no circumstances should a shovel have to wait while one train is pulled out and another set in. That is the object of having through double tracks at the shovels, so that cars can be pushed in a continuous stream past the shovel dippers.

There is one thing I would like to call to the attention of the Board that you will find in these monthly reports—a comparative efficiency statement. I do not know whether your attention has been called to it or not. For instance, the average for the last six months, if you will permit me to read it, gives the daily number of machines at work as six and a fraction. The hours under steam were 9,390. The hours at work were 4,289. The hours of what the men themselves call unavoidable delays were 1,491. The hours of delay due to derailments, switching, hauling material to dumps, and other causes other than unavoidable delays—they used that expression because they did not want to admit that those delays were avoidable—were 3,610. In other words, the percentage of the time under steam lost by avoidable delays was 35 per cent. The number of cubic yards loaded per hour while under steam averaged 60.

General ABBOT. Was that in bulk or place measurement?

Mr. WALLACE. In place; the equivalent of solid material. The way these measurements were calculated was this: The daily reports during the month were based on the carloads, but

every month the material was cross-sectioned. That was checked up, and if in a previous month the sum was too high, it was modified by the cross sections at the end of the month, so as to adjust the figures and make them equivalent to the solid measurements.

The CHAIRMAN. Part of that unavoidable delay, I suppose, is due to moving the shovel itself forward?

Mr. WALLACE. Part of it is due to that, and part of it to the switching in and switching out of the cars. They called that an unavoidable delay, because there were not track facilities. Every time a train was filled, that train had to get out, and it might be five or ten or fifteen or twenty minutes, sometimes, before another train would come back. They set a reasonable time for that switching, I believe five or ten minutes. They did not call it an unavoidable delay unless the train was delayed over five or ten minutes for each shift. These were small cars, holding only 4 or 5 yards, and there was a great deal of time lost in switching movements and small train loads hauled—80 to 100 yards to the train.

I simply call your attention to this to show the possibilities of economy, even below the costs that are shown here, by greater efficiency. The crux of the entire excavation problem is that these excavating units should never be idle. The material should be blasted ahead of the shovels. The cars should be there to load. The cars should be promptly removed and promptly returned. The number of units you can install is limited. That being the case, the efficiency of the whole work depends on the service that is given in appliances and methods and supervision to keep those units of excavation constantly at work. The more constantly they are at work, not only the quicker but also the cheaper will the work be done. If an engine is derailed the transportation expense is not only increased but also that of excavation, and the general expense is increased, because that depends upon the amount of material divided into the total expense.

Mr. WELCKER. In regard to the quantity of concrete, do you think the figure you have spoken of, 10,000 cubic yards a day for the Gamboa dam, is also applicable to the construction of locks, if a lock-level canal should be built? Do you think it would be possible, for instance, with locks at Bohio or Ancon to put 10,000 cubic yards of concrete into the work per day?

Mr. WALLACE. As far as the material is concerned there would be no difference. The difference would be in the shape and form in which the concrete was placed as to the ability to work in that much.

Mr. WELCKER. Do you think it would be much lower?

Mr. WALLACE. I should think it would be lower; of course it is understood that this 10,000 yards a day is a large quantity. It is what I would consider a maximum possibility, but I think at the Gamboa dam it would probably never be necessary to put in over half that quantity, or probably a fourth of it.

The CHAIRMAN. One thousand yards a day for 300 days would be 300,000 yards.

Mr. WALLACE. It would practically do the work.

Mr. WELCKER. What do you think of the comparative efficiency of labor at the Isthmus, allowing for the climate, and labor in the United States for concrete work?

Mr. WALLACE. Of course it would take more men to do it, but a large part of the work of mixing concrete could be carried on by machinery.

Mr. WELCKER. But I mean building locks. It could not all be done by machinery.

Mr. WALLACE. No; not in locks. I should judge that the results in this country ought to be discounted by 25 to 30 per cent.

Mr. WELCKER. Lower than in the United States?

Mr. WALLACE. Lower than in the United States. In large work that you could do by machinery, where you have a large mass of concrete to put in regardless of having to follow molds and shapes, and so on, you would put more men on it; but of course there again you would come back to the fact that you might put more men on in the United States. So I should judge there would be a difference of 25 to 30 per cent.

Mr. HUNTER. Why do you consider that concrete-mixing machinery is not applicable to the construction of locks?

Mr. WALLACE. I did not say that.

Mr. HUNTER. I understood you did.

Mr. WALLACE. No; I beg your pardon. What I meant to say was that the simpler the forms that you put the concrete in, the simpler and easier it is to do it.

Mr. HUNTER. It does not matter much whether the ultimate form is to be simple or complex, it can be mixed by machinery.

Mr. WALLACE. Yes; but if you have a complex form to put the concrete in you can not put as many yards in that form as you can if you have a more simple form. It is not the mixing. It does not take any more machinery or time to mix one than the other, but it is the working of the material in the mold after it is mixed that I refer to.

Mr. HUNTER. The great bulk of the labor is in the mixing.

Mr. WALLACE. Not if you do it by machinery.

Mr. HUNTER. I mean if you mix it by hand.

Mr. WALLACE. I would not consider mixing it by hand.

The CHAIRMAN. What do you estimate as the comparative value of negro labor on the Isthmus with that of Italians, Hungarians, Poles, and negroes in the United States?

Mr. WALLACE. The labor we used when I was on the work was about one-fourth as efficient as the trained labor I have been accustomed to use north of the Ohio River in the United States, and about one-half as efficient as the negro labor I have been accustomed to use in Louisiana and Mississippi.

The negro labor on the Isthmus is now, or was last winter when I was there, at what you might call a maximum inefficiency, for this reason: The labor was used by foremen who did not understand how to use it, who were not familiar with their men, who were not familiar with their work. The amount of labor required there was so large that it was at a premium, and the foremen who had men at work for them were so anxious to keep them that they would put up with all sorts of insubordination. There was not the discipline that there will be when the work is properly officered and the men are trained, and when the men are there in sufficient numbers so that if they are discharged from the work they will not be able to get food to eat until they get another position. That is going to make a great deal of difference. It will materially raise the efficiency of that labor.

I had one batch of 25 foremen sent me from the United States to superintend track work, and none of them had ever laid a rail of track in their lives. They did not know how to tamp a tie, and those men had to teach the negroes, who did not know how to do anything. Of course the result was an inefficient one. You could not expect anything else.

But those matters will rectify themselves when the work gets under way. You can not expect to have a complete organization of 25,000 or 30,000 efficient men, an army of all classes of labor put into the field, and have it spring out of the earth and be formed in a month, or even in a year. It takes time. You have to have your troops seasoned and they have to be drilled and selected.

Mr. GUÉRARD. Up to what point on the Atlantic side do you think it would be advantageous to use dredges?

Mr. TINCAUZER. From the Atlantic to any point on the canal.

Mr. WALLACE. Well, at least as far as Bohio, and possibly beyond.

Mr. GUÉRARD. Do you think fuel oil can be used there to advantage in substitution for coal?

Mr. WALLACE. I would prefer coal at $4 a ton to fuel oil. I do not know how it is in Europe, but in this country we have not yet used fuel oil long enough to determine accurately its effects on boilers, and so on.

Mr. HUNTER. Nor have we, Mr. Wallace. That is just the difficulty.

Mr. WALLACE. Another difficulty about fuel oil is that it has to be used with some degree of care, and requires a little higher order of supervision than with ordinary coal.

Mr. WELCKER. And intelligence?

Mr. WALLACE. Yes; more intelligence.

Permit me to make a remark about power. I do think it is of the utmost importance that the Gamboa dam, if it should be a part of the plan, should be built at the earliest possible date, and that electric power should be used. It can be used for the drills, for lighting, and for many other purposes. It can also be used for night work. It is possible to use it partly in transportation and partly in connection with some of the dredging machinery, particularly the pumping, and things of that kind. Of course you can not tell what the developments might be. It would not be economy to change the steam shovels or the engines that are already on the ground, but there are so many ways in which it could be used that it would surely pay for the extra cost of putting in the machinery after the dam is constructed. You would not be justified in building the dam to create electric power, but having the dam, I think you would certainly be justified in the installation of electric machinery.

Mr. HUNTER. In one of the papers that was read this morning, your figures on efficient work of steam shovels are 800 yards per day and twenty-one days per month. You will perhaps remember those figures in your paper. Does that mean that you reckon on two hundred and fifty working days per year, and not more in that climate, with the conditions there, or is the average of twenty-one days per month founded on other considerations? In other words, how many efficient working days do you reckon on the Isthmus?

Mr. WALLACE. I consider that, month in and month out, year in and year out, we should get a minimum of twenty-one working days per month. My experience there was that we were able to average about twenty-three or twenty-four days a month in the wet season and the dry season together. I would expect to work more than twenty-one days. I would expect to load more yards than 800 per day, but in making up these figures I wanted to be beyond all doubt on the safe side.

Mr. GUÉRARD. Will there be found, without much difficulty, sand, gravel, and stone for the construction of the lock at Ancon-Sosa?

Mr. WALLACE. There is plenty on the Isthmus, but I should not judge there would be an abundance of them in the immediate vicinity—I mean in the actual vicinity of Ancon. It would have to be brought from some distance. Of course it is true that you could manufacture it by crushing the rock right out of Ancon Hill.

Mr. HUNTER. Have you not already said, Mr. Wallace, that the best sand for concrete purposes comes from Panama Bay?

Mr. WALLACE. Yes; I say it is not right at that particular point, but you would get it from the same place from which you would get the other. This is true, that the sand would be more convenient there than probably at any other lock.

Mr. HUNTER. Have you any acquaintance with the quality of the rock in that Ancon-Sosa saddle? Do you know what class of rock it is?

Mr. WALLACE. We have almost everything in Ancon that is found on the Isthmus. I do not know about the other hill. I never examined that, but in Ancon Hill proper there is some rock of a limestone nature; there is basalt and trap, and there are shales.

Mr. GUÉRARD. Do you think there would be any difficulty in obtaining the necessary material to construct a lock at Ancon?

Mr. WALLACE. I do not think there would be. In other words, I think, so far as that particular locality is concerned, the question of material need not cut any figure as compared with the lock at any other locality, as there is so much of it. I judge that was the intent of the question.

The CHAIRMAN. There is harder rock in the vicinity of Ancon than there is anywhere else on the Isthmus. I mean in large batches.

Mr. GUÉRARD. Will there be any difficulty in deepening and maintaining the maritime channel at Panama to 40 feet?

Mr. WALLACE. I do not see anything in the way. Of course there are places where there will be some rock to excavate, but there should be no more and no less difficulty than in any channel where you encounter that kind of formation. I have not taken any borings to determine how much rock there is in that channel; the French records show this.

Mr. GUÉRARD. How much dredging has been done in the maritime channel at La Boca to keep it clear for 21 or 22 feet?

Mr. WALLACE. I think there has been almost continuously at work there a dredge with a capacity of about 2,500 cubic yards a day. It has not been working continuously to that capacity, but there has been one in commission. Sometimes it would be out of commission or it would be idle for a few days or a week or two at a time, repairing machinery or something of that sort, but one dredge has been sufficient to keep that channel open as it was constructed.

Mr. WELCKER. More dredging is necessary on the sea side.

Mr. WALLACE. The drift of the current seems to bring the sand along the coast and silt up the channel, although some sediment is occasionally brought down by the Rio Grande.

Mr. NOBLE. What proportion do you think that would be compared with the amount brought in by the shore currents?

Mr. WALLACE. I think there is more brought in by the shore currents. I did not make any examination to determine that definitely. That was placed under Mr. Harper, an engineer, some months before I left there, and he was supposed to investigate all those things, but up to the time I left he had not made a report.

Mr. STEARNS. Is it not true that the channel has been widened as well as maintained?

Mr. WALLACE. It has to some extent; yes. The situation there, I should judge, has been and will always be this: That between the tidal locks and the deep water in the sea one dredge will always have to be maintained, but I think one dredge will be sufficient to always keep the channel open to a proper depth and width.

Mr. HUNTER. Are you assuming in that answer, Mr. Wallace, that there will be a tidal lock at Miraflores?

Mr. WALLACE. Yes.

Mr. HUNTER. Suppose the tidal lock were in the Ancon-Sosa saddle?

Mr. WALLACE. You would have to have a dredge available there all the time. You might not have to have it in continuous operation. By working it a comparatively short time it might keep the outer channel clear; but I am judging simply from what I saw when I was down there and from my general observations as to the Rio Grande River and the work being done there, that with a tidal lock at Miraflores a dredge would be necessary. Now, a dredge would be necessary in any case, although it might not have to work over thirty days in the year.

Mr. WELCKER. Is it known to you, Mr. Wallace, that there is great difficulty now in retaining the depth of 22 feet in the channel of La Boca after it is dredged to that depth, and that in half a year that depth may diminish to 15 feet if dredging is not constantly continued?

Mr. WALLACE. I have not heard of any such great filling as that. If you have even a 40-foot channel, a certain amount of material would come in each day in each month, but that should not be any more for a deep channel than a smaller one. Your source of supply would not be increased by the depth of the channel. The ability to catch the material would of course be increased slightly, but if you have a depression at all and you create the conditions that are going to cause sediment to catch there, I do not think the increased depth would materially increase the accumulation of the sediment. It might do so to some extent.

Mr. WELCKER. Do you think if it were all mud there the difficulties would be increased?

Mr. WALLACE. Yes; it would because it would make it necessary to widen your section and give a flat slope; but that mud, as I understand it, does not occur out where the maximum dredging has been necessary. Around La Boca pier there is a great deal of that mud, and of course the deeper you dredge the channel the flatter the slope will necessarily be; but after you once get your channel it does not mean that any more mud will come into the deep channel than into the shallow one, practically. I am speaking on the theory now that you do not increase the supply of mud that comes down there in suspension.

The CHAIRMAN. I suppose if we have finished with Mr. Wallace we ought to make a statement to that effect.

Mr. RANDOLPH. I move that we give Mr. Wallace a vote of thanks for the papers he has submitted and for the able way in which he has informed us of his views on the subject.

Mr. HUNTER. And especially the members of the Board who are strangers here are very much indebted to Mr. Wallace for the trouble he has taken and for the free frank manner in which he has laid his acquaintance with this matter at the service of the Board.

The CHAIRMAN. I think there is no doubt of the members of the Board all subscribing to that sentiment, and I will consider the motion of Mr. Randolph adopted and pronounce that as the action in this case.

Mr. WALLACE. Mr. Chairman, I wish to thank you and the Board for the kindness with which I have been treated. It has been not a burden but a pleasure to have this opportunity to appear before you and meet you all. If I can be of any further service I will be only too glad to render it.

The CHAIRMAN. I think it likely we may want to ask you some questions later on, but we evidently can not think of them just now.

The Board thereupon adjourned.

Appendix K.

SUMMARY OF EXCAVATION AT CULEBRA FROM JULY 1, 1904, TO OCTOBER 1, 1905.

Isthmian Canal Commission,
Department of Construction and Engineering,
Panama, October 14, 1905.

Dear Sir: As per your request of Mr. Dose, I beg to hand you herewith report of the division engineer at Culebra for month ending September 30, 1905, and a tabulated statement showing approximate expenditure and distribution of same for fifteen months, ending September 30, 1905; also approximate cost per cubic yard for material handled during that period, compiled from monthly reports.

The column headed "Installation of plant" does not enter into the cost per cubic yard, but is partly taken up by an arbitrary charge of 6 cents per yard.

Under "Installation of plant" in summary of report is also included an item for rebuilding cars, locomotives, etc., by mechanical department, amounting to $158,483.85 which has not been included in the monthly reports.

Yours, truly,

Jno. F. Stevens,
Chief Engineer.

Gen. George W. Davis,
Chairman Board of Consulting Engineers,
Washington, D. C.

Cost of work at Culebra from July 1, 1904, to October 1, 1905.

Month.	Cubic yards excavated.	Arbitrary charges.		Mining.		Excavating.		Maintenance of tracks.	
		Total cost.	Cost per cubic yard.	Total cost.	Cost per cubic yard.	Total cost.	Cost per cubic yard.	Total cost.	Cost per cubic yard.
1904.									
July	31,599			$2,458.18	$0.0778	$5,019.32	$0.1600	$3,846.82	$0.1210
August	35,056			3,129.97	.0800	4,626.49	.1330	2,701.38	.0770
September	25,220			3,447.89	.1281	3,806.61	.1510	1,105.98	.0440
October	19,695			1,923.66	.0977	1,916.08	.0973	1,644.54	.0835
November	28,860			3,397.34	.1180	2,550.74	.0884	2,465.52	.0853
December	42,935	$1,395.39	$0 0325	4,802.52	.1119	3,098.05	.0722	4,360.57	.1016
1905.									
January	70,650	4,239.00	.0600	7,753.26	.1097	5,587.28	.0791	4,284.63	.0606
February	75,200	4,512.00	.0600	6,624.33	.0880	6,386.86	.0849	4,330.36	.0576
March	132,840	7,970.40	.0600	9,956.12	.0750	9,369.96	.0705	5,757.93	.0433
April	126,749	7,604.93	.0600	9,266.71	.0732	11,367.26	.0897	5,663.72	.0447
May	75,935	4,556.10	.0600	8,877.87	.1155	9,031.21	.1183	7,478.55	.0965
June	76,905	4,614.30	.0600	8,407.99	.1093	14,511.96	.1888	8,453.65	.1099
July	78,570	4,714.20	.0600	9,658.66	.1229	12,033.84	.1532	9,011.06	.0893
August	49,210	2,952.60	.0600	11,575.24	.2352	12,334.78	.2506	7,354.03	.1494
September	41,885	2,513.10	.0600	11,203.76	.2675	9,412.22	.2247	7,124.71	.1701
Total	911,309	45,072.03	.0494	102,483.50	.1125	111,052.66	.1218	73,583.35	.0807

Cost of work at Culebra from July 1, 1904, to October 1, 1905—Continued.

Month.	Transportation.		Dumps.		General expense.		Totals.		Installation of plant covered by arbitraries; cost.
	Total cost.	Cost per cubic yard.	Total cost.	Cost per cubic yard.	Total cost.	Cost per cubic yard.	Total cost.	Cost per cubic yard.	
1904.									
July	$4,503.00	$0.1420	$2,062.00	$0.0650	$2,493.35	$0.0800	$20,382.67	$0.6450	$76.18
August	2,976.47	.0850	1,448.39	.0410	2,730.38	.0780	17,613.08	.5024	118.48
September	3,020.44	.1200	1,279.45	.0510	1,427.68	.0560	14,088.05	.5586	363.02
October	2,252.47	.1143	1,107.79	.0562	1,492.27	.0758	10,336.81	.5248	310.83
November	2,635.35	.0912	778.27	.0270	1,854.41	.0643	13,681.63	.4741	775.66
December	4,747.62	.1106	1,750.95	.0408	1,339.96	.0312	21,495.06	.5008	1,402.59
1905.									
January	6,525.05	.0923	2,894.42	.0410	2,494.03	.0353	33,777.67	.4780	10,696.15
February	7,100.00	.0945	2,865.72	.0381	3,169.70	.0422	34,988.97	.4653	19,109.34
March	14,682.94	.1105	6,291.67	.0471	3,503.24	.0262	57,532.16	.4328	25,630.05
April	21,648.01	.1708	5,614.98	.0443	5,321.93	.0420	66,487.55	.5247	19,701.20
May	21,407.72	.2820	6,289.65	.0828	6,293.13	.0830	63,934.23	.8381	17,977.74
June	28,506.97	.3707	8,209.20	.1067	6,307.92	.0820	79,011.99	1.0274	20,240.27
July	32,883.77	.4185	9,408.46	.1197	5,642.18	.0718	81,352.17	1.0354	127,111.86
August	30,248.29	.6147	4,889.21	.0993	6,363.66	.1203	75,717.81	1.5385	43,818.33
September	19,405.81	.4633	5,229.39	.1248	5,474.71	.1307	60,363.70	1.4411	59,639.62
Total	202,543.91	.2222	60,119.55	.0659	55,908.55	.0613	650,763.55	.7141	[a] 505,455.17

[a] The arbitrary charges are added to cover the installation of plant. Only $45,072.03 of this $505,455.17 have been included in the total cost of $650,763.55.

Amount charged by the Bureau of Motive Power and Machinery for the cost of labor for rebuilding French locomotives, dump cars, cranes, etc., total for fifteen months, $158,483.85. The above amount is added to the cost of installation of plant and shows in the grand total.

Appendix L.

TRAFFIC CAPACITY OF A LOCK CANAL WITH SUMMIT LEVEL AT ELEVATION 85.

By Alfred Noble and Joseph Ripley.

The lockage system will comprise a double flight of three locks at Gatun with lifts of about 28½ feet each, one lock in duplicate at Pedro Miguel with lift of about 30 feet, and a double flight of two locks at Sosa with lift varying with the tide.

It is assumed that when the traffic approaches the full capacity of the locks one flight of either two or three locks will be used for ships bound down and the other for ships bound up. When thus used the number of locks in a flight does not affect the capacity for traffic except as regards unforeseen accidents. The Gatun flight will be taken for this inquiry.

In order to develop the full capacity of a lockage system, ships must always be awaiting lockage; hence, made fast to the approach pier. Since it is assumed that each flight is to be used for ships moving in one direction, it will be further assumed that the bow of the waiting ship lying at the approach pier next in order for lockage will be 100 feet from the gate; and it is also assumed that on entering the lock it will acquire a speed of 1.7 miles per hour (150 feet per minute) while moving 300 feet, requiring four minutes; that it will continue at this speed until its stern is within 150 feet of the gate and will then stop within 200 feet in two minutes forty seconds. The length of the lock is taken as 1,065 feet between gates, giving a usable length of 1,000 feet as adopted by the Board. Length of ship taken at 500 feet, distance moved is then $100 + 500 + 50 = 650$ feet.

Time from place at pier to stop in lock:		Min.	Sec.
First	300 feet in	4	00
Next	150 feet in	1	00
Last	200 feet in	2	40
Total	650 feet in	7	40

At the St. Marys Falls Canal, where ships pass the Poe lock in both directions, waiting ships stop 300 to 450 feet from the gates to permit departing ships to pass out from the lock. The observed time for entering the lock from a stop at this greater distance varies from four minutes upward, and nine minutes is a fair average of actual time consumed from pier to entrance into lock chamber, with a movement about 300 feet greater than taken above.

At the Poe lock, with unsatisfactory gate machinery, the opening or closing of a gate requires from two to three minutes. At the Amsterdam Canal the gates are operated in 1 minute 20 seconds. With suitable machinery no doubt is entertained that the gates of the Poe lock would be operated in less than two minutes; neither is it doubted that the gates of the Panama Canal could be operated in the same period.

The total cross-sectional area of the six filling culverts in the Poe lock is 384 square feet, or 64 square feet for each culvert. The culverts are under the lock floor. The outlets from the culverts are not so shaped as to facilitate the discharge of water, resulting in a low coefficient of discharge of 0.5 to 0.6. The permissible speed of filling or emptying depends mainly on whether ships are lying in the vicinity awaiting lockage, as the too sudden opening of all the culverts sets up a current sufficient to part the lines of such waiting ships. In such cases the routine is to open only two culverts at first; when the ship (if bound up) has been lifted 3 feet, which requires about 1 minute 49 seconds, two more culverts are opened, lifting the ship about 4 feet in the next

1 minute 20 seconds. All are then opened, filling the lock in a further period of 6 minutes 14 seconds, or 9 minutes 22 seconds in all. These periods are calculated with the coefficient of 0.5 and conform to observations. When no ships are in the lock approaches, all the valves can be opened as soon as the ship's lines are fast. At least five lines are put out, single parts. The lines are in place and taut by the time the gates are closed. No harm results to ships ascending if all six culverts are opened at once; with descending ships, when no others are waiting, all the culverts may be opened after the first minute or so, when the lines begin to draw across the coping so as to keep taut.

For the operation of passing from one lock to another, the distance to be moved is the length of the lock, which at Panama will be 1,065 feet. With the same speed as before, the time required from start in one lock to stop in the next will be:

	Feet.	Minutes.	Seconds.
To acquire speed of 1.7 miles per hour moving	300	4	00
To move at rate of 1.7 miles per hour	565	3	46
To reduce speed to a stop in	200	2	40
Total	1,065	10	26

Taking into consideration the effect on waiting ships of opening the culverts as observed at the St. Marys Falls Canal and the relative cross-sectional areas of the approach channels, about 2,750 square feet at the St. Marys Falls Canal and about 11,500 at the Panama Canal, there is no reason why a much larger culvert area could not be used at the latter canal than at the former. But assuming it to average only 250 square feet during the process of filling or emptying, taking a coefficient of 0.6 for cases where the water is drawn into a culvert for the length of a lock chamber and discharged through another of equal length, and a coefficient of 0.7 for cases where the water passes in culvert only half the distance, the time required for filling or emptying becomes, for a lift of 28¾ feet (the lift at each of the Gatun locks for the 85-foot level)—

	Min.	Sec.
For filling upper lock or emptying lower lock	13	27
For emptying upper lock or filling lower lock	11	06

The foregoing embraces all the elements for a calculation of what may be called the theoretical capacity of the canal. When a ship has passed from the upper to the lower lock and the middle gates are closed behind it, the upper lock will be filling while the lower lock is emptying, and as the ship is passing out of the lower lock into the next level the following ship will be entering the upper lock. The cycle may be taken as beginning and ending with the successive openings of the upper gates, and will be as follows:

	Min.	Sec.
Ship moving from stop into upper lock	7	40
Closing upper gates	2	00
Emptying upper lock	11	06
Opening middle gates	2	00
Ship moving into lower lock	10	26
Closing middle gates	2	00
Filling upper lock	13	27
Opening upper gates	2	00
Interval between ships	50	39

With this interval the yearly capacity of the two flights would be $\frac{365\times24\times60\times2}{50.65}=20,754$ lockages.

The number of lockages above given could not be realized in actual practice. The number of ships arriving per day would not be uniform. On some days there would not be enough ships to require the continuous operation of the locks, while on other days ships in considerable number might be awaiting lockage. As the traffic increases the loss of time to ships will increase in more rapid ratio. At the St. Marys Falls Canal the average time required for passing through

the canal and lock was about five hours in 1895. Three years later, when the lockage capacity had been greatly increased, the time required was about one and one-fourth hours. In 1894 the time required was about four hours; in that year the number of ships passed was about 0.62 of the number that would have been shown theoretically possible by a calculation similar to the foregoing. If the following year had been taken this coefficient would have been 0.68. This coefficient represents the reduction below theoretical capacity due to all causes, such as dilatory movements, repairs during the season, irregularity in arrival of ships, etc., for a condition when the average delay, beyond the time actually required for lockage, is about four and one-half hours. Applying this to the above calculated number of lockages possible in a year, there results $20,754 \times 0.68 = 14,113$ lockages.

To transform this into tonnage it is necessary to estimate the average tonnage of ships when this traffic is reached. It does not seem unreasonable to estimate this at 5,000 tons net register per ship, which would give an annual traffic of $14,113 \times 5,000 = 70,560,000$ tons, with lockages of single ships only; but many lockages will be made of two to four ships per lockage, largely increasing the ultimate capacity of the system. This is illustrated at the St. Marys Falls Canal, where, with an average lockage in the Poe lock of about 4,500 tons, an aggregate of 10,000 to 12,000 tons in a lockage is not unusual. The average tonnage per lockage is increasing steadily, being 4,677 tons net register for the months of September and October of the present year, the average number of ships per lockage being 1.74 and the average net tonnage per ship being 2,681. Remembering that the capacity of the Poe lock has not nearly been reached, and that as the traffic increases the number of ships per lockage is likely to increase, it appears probable that the number of ships per lockage will ultimately be two or more. The great locks recommended by the Board for the Panama Canal would be well adapted for what may be called fleet lockages, and would contain four or more ordinary tramp steamers of moderate draft of the type now in use, aggregating 10,000 tons or more. If the type should change and ships of much larger dimensions come into general use, an equal or greater tonnage could be passed per lockage, and the annual tonnage might become 80,000,000 tons, with ample allowance of time for such repairs as might be required.

This estimate of traffic capacity is further supported by the record at the St. Marys Falls Canal, where a total of 6,622,239 tons net register passed through the Poe lock in the months of September and October, 1905. This is at the rate of about 39,750,000 tons per year of twelve months. This tonnage was passed in 1,416 lockages, requiring 817 hours 31 minutes, counting for lockage the interval from the moment when the bow of the first ship enters the lock to the moment when the stern of the last ship leaves it. The lockage should be considered as occupying a longer interval than this, and there should be added the time required to move from the stop at the approach pier to the lock and the time required to move from the outlet of the lock past a waiting ship. Taking the first-named distance at 400 feet and the last named at 400 feet plus a ship's length, say 500 feet more, the two movements are estimated to require—

	Min.	Sec.
For movement to lock—		
First 300 feet, 4 minutes; next 100 feet, 40 seconds =	4	40
For movement from lock (average speed assumed, 3 miles per hour)—		
To move 900 feet	3	25
Total for each lockage	8	05
	Hrs.	Min.
1,416×8 minutes 5 seconds=11,446 minutes=	190	46
Reported time, quoin to quoin	817	31
Lockages occupied	1,008	17
Hours in two months	1,464	00
Lock not in use during two months	455	43

It would not be safe to take all of this period as available for lockage, because this would require a constant supply of waiting ships, resulting in delays that would become intolerable to shipping interests; but probably the use of 300 hours of the 455 would be practicable, which

would add 30 per cent to the tonnage, making the capacity of the Poe lock upward of 50,000,000 tons in twelve months.

In order to apply this to the Panama Canal an estimate must be made of the relative capacity of a flight of two or more locks and a single lock.

A single lock would pass the greatest traffic when ships moved in opposite directions alternately. Ships awaiting lockage would have to lie at a greater distance from the lock than when all are moving in the same direction, and this will be taken at 400 feet. The waiting ship would not usually begin moving toward the lock until the outgoing ship had completely passed it. This requires a movement of the outgoing ship of 1,650 feet. On this basis the passage through a single lock like the Poe lock would require:

	Min.	Sec.
From stop at approach pier to stop in lock	9	40
Closing gates	2	00
Filling or emptying lock	9	22
Opening gates	2	00
Moving out:		
Acquiring speed of 1.7 miles, 300 feet (Min. 4)		
Increasing speed to 4.4 miles, 1,350 feet (Min. 5)		
	9	00
Interval between two ships	32	02

With a flight of two locks, the waiting ship would lie, say, 100 feet from the lock, and the interval would be as follows:

	Min.	Sec.
From stop at approach pier to stop in lock	7	40
Closing gates	2	00
Filling or emptying lock (9 minutes 22 seconds×0.707)	6	36
Opening middle gates	2	00
Moving into next lock:		
Acquiring speed of 1.7 miles, 300 feet (Min. 4, Sec. 00)		
Moving at this rate, 300 feet (Min. 2, Sec. 00)		
Reducing to stop, 200 feet (Min. 2, Sec. 40)		
	8	40
Closing middle gates	2	00
Emptying or filling lock	9	22
Opening outer gates	2	00
Interval between ships	40	18

The capacity of the St. Marys Falls Canal would be reduced by introducing another lock of the same dimensions, in the ratio 40 m. 18 s. : 32 m. 32 s., or 20½ per cent, or from 50,000,000 tons in twelve months to 39,750,000 tons. With duplicate locks the capacity would be:

	Tons.
For two flights of one lift (see above)	100,000,000
For two flights of two lifts (as above)	79,500,000

While the larger locks of the Panama Canal will not be operated quite as quickly, the average tonnage per lockage will be so much greater that a traffic of 80,000,000 tons can be handled at the locks without difficulty.

As before stated, the estimates of time for lockage and of traffic capacity for the Panama Canal are made for locks of a usable length of 1,000 feet. With locks of a usable length of 900 feet the estimated capacity would be somewhat greater because a ship would have to move a shorter distance in the locks.

The following tables have been compiled from the records of the St. Marys Falls Canal:

St. Marys Falls Canal, Michigan.

Date.	Lockages.						Average time of passage of canal 1⅞ miles long, including lockage.	
	Weitzel lock.			Poe lock.				
	Number.	Average time.	Number of ships.	Number.	Average time.	Number of ships.	Actual.	Necessary.
		m. s.	—		*m. s.*		*h. m.*	*h. m.*
1887	4,165	38 47	9,355					
1888	3,845	39 09	7,803					
1889	4,684	40 03	9,579					
1890	4,970	41 40	10,557				4 34	2 54
1891	4,981	41 11	10,191				4 17	2 50
1892	5,867	42 13	12,580				5 02	3 49
1893	5,553	40 40	12,008				4 13	3 15
1894	6,431	40 12	14,491				4 36	4 08
1895	7,039	39 06	16,793				5 46	4 58
1896	5,462	36 35	11,035	961	56 45	2,406	2 45	2 09
1897	1,577	38 59	2,677	4,390	43 14	10,135	2 16	1 42
1898	2,682	33 30	4,513	4,326	43 05	9,545	2 13	1 11
1899	4,007	32 05	6,935	1,382	46 58	9,545	2 19	1 14
1900	4,153	20 43	7,093	4,326	34 21	9,276	2 11	1 10
1901	4,074	24 22	7,004	4,337	36 02	8,833	2 11	1 34
1902	4,149	22 09	6,469	5,278	37 58	11,119	2 37	1 29
1903	3,467	20 37	5,173	4,928	34 45	9,070	2 21	1 24
1904	3,219	22 43	4,747	4,074	34 30	7,406	2 18	1 23
1905	4,469	22 57	6,561	5,288	35 15	9,458	2 11	1 39
	84,794	34 28	165,564	42,290	38 47	86,793	3 13	2 16
1895.								
April	65	32 12	96					
May	1,034	38 28	2,443					
June	1,050	39 13	2,875					
July	1,071	39 15	2,838					
August	1,063	39 35	2,809				5 46	4 58
September	955	38 19	2,218					
October	919	37 09	1,878					
November	768	42 07	1,447					
December	114	43 27	189					
Total	7,039	39 06	16,793					
1896.								
April	235	39 07	426					
May	997	39 06	2,341					
June	1,003	36 07	2,144					
July	1,049	35 12	2,215					
August	786	37 17	1,576	172	50 48	527	2 45	2 09
September	579	36 55	1,018	221	84 15	610		
October	508	32 45	842	253	76 01	583		
November	288	36 09	442	271	55 19	600		
December	17	44 39	31	44	58 19	86		
Total	5,462	36 35	11,035	961	66 45	2,406		
1904.								
May	14	18 43	17	262	23 44	419	1 12	0 48
June	339	21 46	529	503	33 05	916	2 00	1 17
July	631	22 06	944	667	35 49	1,225	1 55	1 25
August	629	21 32	901	677	35 41	1,245	1 57	1 21
September	551	22 01	770	622	36 11	1,141	2 38	1 30
October	552	24 14	851	657	36 30	1,273	2 39	1 31
November	477	24 49	698	568	33 41	982	2 42	1 20
December	26	22 09	37	118	34 11	205	4 12	1 31
Total	3,219	22 43	4,747	4,074	34 30	7,406	2 18	1 23

St. Marys Falls Canal, Michigan—Continued.

Date.	Lockages.						Average time of passage of canal 1⅞ miles long, including lockage.	
	Weitzel lock.			Poe lock.				
	Number.	Average time.	Number of ships.	Number.	Average time.	Number of ships.	Actual.	Necessary.
1905.		*m. s.*			*m. s.*		*h. m.*	*h. m.*
April	97	26 19	126	181	47 30	377	3 39	2 59
May	628	23 16	961	702	35 18	1,273	1 52	1 44
June	654	22 11	936	684	35 18	1,250	1 52	1 43
July	685	21 48	976	732	36 08	1,367	1 57	1 47
August	703	21 49	1,031	748	32 20	1,266	1 41	1 19
September	628	22 21	886	655	35 19	1,157	2 10	1 32
October	566	23 29	871	761	34 03	1,325	2 27	1 33
November	469	26 18	708	619	35 27	1,104	3 12	1 48
December	44	25 33	66	206	29 13	339	2 27	0 55
Total	4,469	22 57	6,561	52 88	35 15	9,458	2 11	1 39

Average time of lockage through the Canadian lock, 15 minutes.
A single steamer has been locked through the Weitzel lock in 10 minutes.
A single steamer has been locked through the Poe lock in 11 minutes.
A single steamer has been locked through the Canadian lock in 8 minutes.
The yearly average time of passage per ship has been 1 to 6 minutes less than the average time of lockage.

Maximum number of lockages in a day.

WEITZEL LOCK.

Date.	Number of lockages.	Number of ships.	Registered tonnage.	Freight tonnage.
			Net tons.	*Net tons.*
July 19, 1895	41	100	79,197	58,897
July 28, 1895	41	85	89,574	88,298
July 9, 1896	41	81	68,324	54,813

POE LOCK.

May 15, 1899	36	93	118,601	75,747

Traffic statement for October, 1905.

Item.	Poe lock.	Weitzel lock.	Canadian lock.	Total.
Number of ships	1,325	871	712	2,908
Lockages	761	566	520	1,847
Time spent in making lockages (hours)	432	221	131	784
Registered tonnage	3,490,985	993,303	660,910	5,145,198
Freight tonnage	5,113,879	340,065	592,243	6,046,187

Appendix M.

TIME REQUIRED TO PASS A FLIGHT OF LOCKS AT BOHIO OR AT GATUN, ON THE PANAMA CANAL.

By J. W. Welcker.

Time of lockages.

Movements of lockage.	Time in minutes.			
	I.	II.	III.	IV.
	Minutes.	*Minutes.*	*Minutes.*	*Minutes.*
1. Vessel entering first lock chamber	9	11	15	15
2. Closing first set of gates	4	5	5	7
3. Filling or emptying first lock chamber	24	28	19	28
4. Opening second set of gates	5	7	6	8
5. Vessel entering second lock chamber	9	11	15	15
6. Closing second set of gates	5	7	6	8
7. Filling or emptying second lock chamber	24	28	19	28
8. Opening third set of gates	4	5	6	7
9. Vessel entering third lock chamber	.....	.....	15	.....
10. Closing third set of gates	.....	.....	6	.....
11. Filling or emptying third lock chamber	.....	.....	19	.....
12. Opening fourth set of gates	.....	.....	5	.....
13. Vessel leaving last lock chamber	7	9	12	12
Total	91	111	148	128
Loss of time between each pair of operations at 2 minutes each	16	16	24	16
Time needed for one complete lockage	107	127	172	144
Number of lockages per 24 hours, lockages being performed without any interruption	$13\frac{1}{2}$	$11\frac{1}{3}$	$8\frac{1}{3}$	10

I. French lock, two chambers each. Length, 590.5 feet (180 m.); width, 65.6 feet (20 m.); lift, 36 feet (11 m.); depth on sill, 28 feet (8.5 m.); volume of lift water, 1,414,285 cubic feet.

II. Bohio lock, Isthmian Canal Commission (great chambers), two chambers each. Length, 740 feet; width, 84 feet; lift, 42.5 feet; depth on sill, 35 feet; volume of lift water, 2,641,800 cubic feet.

III. Gatun lock, lock plan of committee of Consulting Board, three chambers each. Length, 1,000 feet; width, 100 feet; lift, 28 feet; depth on sill, 40 feet; volume of lift water, 2,800,000 cubic feet.

IV. Gatun lock, lock plan of committee of Consulting Board, two chambers each. Length, 1,000 feet width, 100 feet; lift, 42.5 feet; depth on sill, 40 feet; volume of lift water, 4,250,000 cubic feet.

EXPLANATION OF THE TABLE.

Movement 1 includes time necessary to approach first set of gates. Loss of time before a vessel being locked has left passage, by a vessel awaiting lockage, is equally included in time, and indicated by movement 13; this figure may be smaller than the former.

Experience in Europe has shown that a vessel of great tonnage is exposed to most serious damage if the surface of the water in the lock chamber descends or rises faster than 0.45 meter (18 in.) per minute. Movements 3, 7, and 11 are calculated accordingly. Cross sections of culverts are to be designed corresponding to that figure and to the total volume of lift water in each lock chamber.

The favorable supposition is made that an approaching vessel always finds the first lock chamber ready for entering—that is, that the first set of gates is open.

It is supposed that the outer set of gates can be opened or closed in less time than the inner sets, this due to the vicinity of the open canal prism. Loss of time between each pair of movements is reckoned only at two minutes, which in practice will prove too small.

It will also prove impossible to continue lockages day and night without any interruption between the end and the beginning of two subsequent lockages. The French Comité Technique and the Isthmian Canal Commission of 1899–1901 both reduced the real capacity of a lock to 50 per cent of its theoretical capacity, calculated in the last line of preceding table.

Each member of the Board may now for himself fix that reduction, and then multiply the real number of lockages with the average tonnage per lockage he thinks to be correct; in that manner he will easily find the total real capacity of the canal for one year for each set of locks.

As the Bohio and Gatun locks consist of a double flight of locks, the daily theoretical number of lockages for these locks will be twice the numbers indicated in the last line of the table.

The favorable supposition is also made that all passing vessels are steamers, and during the lockage will move by their engines.

Appendix N.

EQUIPMENT RECOMMENDED FOR CANAL EXCAVATION, WITH CAPACITY OF EACH UNIT.

By Isham Randolph.

The Committee on Sea-Level Canal.

Gentlemen: Pursuant to your request I present herewith the results of my work in determining the equipment which in my judgment suits best the various parts of the project for a sea-level canal on the Panama route. This presentation is in tabular form. The capacity rating is based upon my personal knowledge of the performance of the various machines scheduled, save in the case of the *Israel Tarte* class of hydraulic dredges. The record of work performed by that dredge is readily available, and there can be no question of the conservatism of my estimate upon what can be accomplished by such dredges. In the case of cableways I am assuming a rather higher average than was obtained on my own work with these devices, but I feel justified therein because of improvements made in their construction since their pioneer work with us. My rating of steam shovels may be considered low, but it is based upon experience in steam-shovel work under conditions far more favorable than those which will obtain in Panama. At the present time we are engaged in excavating a channel in limestone rock 160 feet wide and about 36 feet deep; this rock after being blasted is loaded by powerful modern steam shovels into side-dump cars and hauled by locomotives onto embankments, the average haul being less than a mile. On the top lift the average hourly output was about 67 cubic yards per shovel per hour. On the lower lift that average has fallen to 50 cubic yards per hour per shovel. On the other hand, one of these same shovels, digging in very hard clay, is loading an average of 257 cubic yards per hour. The record in West Neebish (Sault Ste. Marie) rock cut is reported as 535 cubic yards per shovel, loading into cableway skips, ten-hour shifts. This is above the average which the contractors think they can reasonably count upon. You will note that in several instances I suggest hydraulic dredges for removing material overlying the rock. This is in accordance with my own experience on sections A and B of the sanitary district of Chicago. There we used two hydraulic dredges (one of them built upon the bank and launched into a part of section A where the water was impounded by an earth dam) and removed about 1,200,000 cubic yards of such material as these dredges could handle, and when their limit had been reached we pumped the channel dry and completed the work with steam shovels. This is entirely practical, and the results obtained are very economical.

Respectfully submitted.

Isham Randolph.

Equipment recommended for canal excavation, with capacity of each unit.

From—	Classification.		Kind of equipment recommended.	Monthly working capacity.	Time in which one unit will do the work.	
	Rock.	Earth.				
	Cubic yards.	*Cubic yards.*		*Cubic yards.*	*Months.*	*Years.*
Seven-fathom contour to kilometer 10.1	4,090,826		Dipper dredge	52,000	78.7	6.56
		8,692,500	Hydraulic dredge No. 1	500,000	17.3	1.44
Kilometer 10.1 to kilometer 40.6	3,278,234		Cableway	9,500	345.0	28.75
		45,957,093	Hydraulic dredge No. 1	500,000	92.0	7.66
		1,169,064	Cableway	9,500	123.0	10.25
	4,131,573		Steam shovels and cars	9,500	435.0	36.25
		6,972,586	do	9,500	734.0	61.16
Kilometer 40.6 to kilometer 43	2,857,959		do	9,500	300.8	25.00
		3,154,812	Hydraulic dredge No. 2	130,000	24.2	2.00
Kilometer 43 to kilometer 48	14,591,987		Steam shovels and cars	9,500	1,536.0	128.00
		7,383,817	do	9,500	777.0	64.75
Kilometer 48 to kilometer 60	64,708,122		do	9,500	6,811.0	567.60
		42,012,155	do	9,500	4,422.0	368.50
Kilometer 60 to kilometer 62.8	2,191,717		do	9,500	230.0	19.00
		1,614,359	do	9,500	170.0	14.00
Kilometer 62.8 to kilometer 68.75	2,372,010		Cableway	9,500	249.0	20.75
		6,663,910	Hydraulic dredge	130,000	51.2	4.26
Kilometer 68.75 to kilometer 70	2,733,236		Cableway	9,500	288.0	24.00
		863,885	Steam shovels and cars	9,500	91.6	7.60
Kilometer 70 to kilometer 72	1,132,509		Dipper dredge	52,000	21.8	1.81
		1,207,685	Hydraulic dredge	130,000	9.3	.....
Kilometer 72 to kilometer 75.25	.....	2,605,090	do	130,000	20.0	1.66
	102,088,174	128,196,056				

Note.—From kilometer 48 to kilometer 60, total yardage is 106,720,277. One shovel would do this work in 936 years, hence 60 shovels would do the work in 15.6 years and 93.6 shovels would do it in 10 years and 117 shovels would do the work in 8 years, these numbers being for the average of shovels employed for the respective periods. For each of these three cases the minimum and maximum number of shovels employed would be as follows: Minimum 40, maximum 82; minimum 63, maximum 125; minimum 78, maximum 156, respectively.

For dredges of all classes one month is taken as 26 days. For steam shovels and cableways one month is taken as 19 days.

Appendix O.

VITAL STATISTICS.

[Compiled under direction of Col. W. C. Gorgas, U. S. Army, Chief Sanitary Officer.]

Table 1.—EMPLOYEES OF THE PANAMA CANAL COMPANIES, MARCH, 1881, TO APRIL, 1904.

Number of employees and total number of deaths from all causes.

Year.	Number employees.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Total.	Per 1,000.
1881	928	.....	.....	1	2	1	7	11	4	7	8	6	11	58	59.2
1882	1,910	6	17	10	3	7	9	21	18	11	7	9	7	125	65.4
1883	6,287	24	17	19	17	25	24	29	21	50	49	72	76	423	67.2
1884	17,615	61	92	94	63	45	64	88	117	139	161	162	146	1,232	69.9
1885	15,215	104	60	66	52	60	96	109	101	145	104	109	90	1,096	71.3
1886	14,935	71	75	98	91	67	90	98	88	78	61	74	64	955	64.0
1887	16,217	83	53	62	63	104	101	106	108	73	102	99	79	1,033	63.7
1888	13,725	61	68	56	59	35	59	42	41	40	53	49	42	605	44.2
1889	1,826	36	11	14	11	4	1	3	2	1	3	1	1	91	49.8
1890	800	1	2	3	0	2	1	3	5	7	3	1	2	30	37.5
1891	800	2	3	3	3	4	4	2	3	3	6	3	1	37	46.3
1892	800	3	1	1	1	2	3	3	3	1	1	2	1	22	27.5
1893	800	2	1	3	0	2	0	2	4	1	2	1	1	19	23.8
1894	800	1	1	2	2	3	1	2	0	0	2	1	2	17	21.3
1895	1,225	0	1	0	2	5	1	4	2	2	2	5	6	30	24.5
1896	3,715	4	6	2	4	4	12	8	6	14	10	4	5	79	21.3
1897	3,980	10	7	6	10	31	17	7	12	12	3	5	7	127	31.9
1898	3,400	8	9	6	6	9	7	5	8	3	5	5	2	73	10.9
1899	2,500	5	4	4	2	6	4	14	6	3	5	1	3	57	22.8
1900	2,000	7	8	3	3	4	5	10	3	5	4	12	5	69	34.5
1901	2,000	4	0	4	2	0	1	4	3	5	5	3	5	36	18.0
1902	1,500	5	2	4	3	1	2	3	0	4	3	4	2	33	22.0
1903	1,000	12	3	2	7	4	1	2	1	1	0	0	0	33	33.0
1904	750	1	0	0	2	.....	.....	.....	.....	.....	.....	.....	.....	3	
Total	.....	511	441	463	408	425	510	576	556	608	599	628	598	6,283	

Table 2.—EMPLOYEES OF THE OLD PANAMA CANAL COMPANY, MARCH, 1881, TO DECEMBER, 1889, INCLUSIVE.

Number of employees, and total number of deaths by months, yellow fever and malaria.

Year.	Employees.	January.		February.		March.		April.		May.		June.		July.	
		Yellow fever.	Malaria.	Yellow fever.	Malaria.	Yellow fever.	Malaria.	Yellow fever.	Malaria.	Yellow fever.	Malaria.	Yellow fever.	Malaria.	Yellow fever.	Malaria.
1881	928	.....	.....	.....	.....	0	0	0	0	0	0	1	0	3	4
1882	1,910	0	1	1	8	3	0	1	0	3	1	3	1	6	10
1883	6,287	2	5	0	2	0	7	0	2	0	2	2	5	3	11
1884	17,615	3	17	9	36	8	26	6	15	3	9	6	19	8	29
1885	15,215	22	25	9	16	9	13	2	13	19	12	31	23	33	30
1886	14,935	11	23	15	21	23	32	25	28	32	9	44	9	42	13
1887	16,217	19	24	17	8	15	10	12	7	28	11	29	19	25	24
1888	13,725	12	14	12	10	11	11	7	7	6	3	11	8	8	6
1889	1,826	4	8	2	2	2	2	3	1	1	0	1	0	2	0
Total	.....	73	117	65	103	71	101	56	73	92	47	128	84	130	127

TABLE 2.—EMPLOYEES OF THE OLD PANAMA CANAL COMPANY, MARCH, 1881, TO DECEMBER, 1889, INCLUSIVE—Continued.

Number of employees, and total number of deaths, by months, yeltow fever and malaria—Continued.

Year.	Employees.	August.		September.		October.		November.		December.		Total.		Per 1,000.	
		Yellow fever.	Malaria.	Yellow fever.	Malaria.	Yellow fever.	Malaria.	Yellow fever.	Malaria.	Yellow fever.	Malaria.	Yellow fever.	Malaria.	Yellow fever.	Malaria.
1881	928	2	2	0	3	1	4	3	0	1	6	11	19	12.0	20.5
1882	1,910	9	6	3	5	5	1	2	3	0	1	36	40	18.9	20.9
1883	6,287	3	5	1	8	3	11	5	17	1	25	26	100	1.1	16.0
1884	17,615	3	51	8	40	21	51	20	56	33	35	128	384	7.26	21.7
1885	15,215	19	38	24	48	11	35	11	45	9	26	199	321	12.4	21.3
1886	14,935	34	17	32	13	10	13	22	12	18	11	308	201	20.1	13.5
1887	16,217	18	31	16	12	14	27	12	14	11	15	216	202	13.3	12.1
1888	13,725	9	8	7	3	8	7	6	13	5	8	102	98	7.4	7.14
1889	1,826	0	1	0	1	0	1	0	0	0	0	15	16	8.1	8.7
Total		97	159	94	133	73	150	81	160	81	130	1,041	1,384		

NOTE.—Data for Tables 1 and 2 taken from official nominal lists of all the cases of disease and injury coming under observation of the medical officers of the companies. An individual report was made in the case of each death, giving name, nativity, sex, age, date of admission or accident, date and cause of death, with amount of pay due. Each report signed by the medical officer and sent to central office of administration.

PANAMA, *July, 1905.*

TABLE 3.—POPULATION, AND DEATHS FROM YELLOW FEVER AND MALARIA IN THE CITY OF PANAMA, NOVEMBER, 1883, TO JULY, 1905, INCLUSIVE.

[Population estimated.]

Year.	Population.	January.		February.		March.		April.		May.		June.		July.	
		Yellow fever.	Malaria.	Yellow fever.	Malaria.	Yellow fever.	Malaria.	Yellow fever.	Malaria.	Yellow fever.	Malaria.	Yellow fever.	Malaria.	Yellow fever.	Malaria.
1883	14,000														
1884	16,000	8	25	5	38	3	26	0	16	1	17	2	19	11	23
1885	18,000	17	65	3	16	8	26	6	20	28	32	38	98	21	60
1886	18,000	22	30	27	47	42	48	39	30	44	33	31	36	23	56
1887	18,000	17	36	17	29	15	33	12	24	27	35	40	42	51	38
1888	18,000	7	30	5	35	1	35	4	24	7	20	12	40	10	41
1889	17,000	4	47	9	19	4	24	7	17	7	26	1	17	0	23
1890	16,000	0	20	0	14	0	16	0	10	0	14	0	11	0	26
1891	16,000	0	14	0	16	0	14	0	19	0	12	8	25	1	17
1892	16,000	0	26	0	8	0	12	0	12	1	6	0	7	0	16
1893	16,000	1	8	0	10	0	9	0	18	0	10	0	9	0	10
1894	16,000	0	8	0	5	0	6	0	11	0	9	0	16	0	17
1895	16,000	0	12	0	7	0	8	0	8	0	6	0	15	0	15
1896	17,000	0	15	0	19	0	7	0	16	0	13	0	15	0	20
1897	17,000	0	19	0	8	0	13	9	11	11	30	15	15	8	35
1898	17,000	0	14	0	12	0	12	0	15	0	14	0	10	0	17
1899	17,000	0	22	0	15	0	6	0	11	4	11	20	13	22	21
1900	17,000	5	13	3	7	5	8	12	19	10	18	11	19	25	18
1901	17,000	2	9	1	7	0	11	1	9	0	2	0	12	1	8
1902	19,000	0	15	0	15	0	19	4	10	2	13	15	76	38	88
1903	18,000	12	25	7	15	5	15	1	14	3	10	3	17	5	13
1904	18,000	4	16	0	16	0	16	0	10	1	15	1	14	1	12
1905	20,000	2	20	8	8	3	1	0	1	1	1	6	7	2	3
Total		101	492	85	366	86	365	95	325	147	347	203	533	219	577

TABLE 3.—POPULATION, AND DEATHS FROM YELLOW FEVER AND MALARIA IN THE CITY OF PANAMA, NOVEMBER, 1883, TO JULY, 1905, INCLUSIVE—Continued.

Year.	Population.	August.		September.		October.		November.		December.		Total.		Per 1,000.	
		Yellow fever.	Malaria.	Yellow fever.	Malaria.	Yellow fever.	Malaria.	Yellow fever.	Malaria.	Yellow fever.	Malaria.	Yellow fever.	Malaria.	Yellow fever.	Malaria.
1883	14,000	.....	.....	.....	.....	.....	.....	3	18	6	17	9	35	[a]3.86	[a]15.00
1884	16,000	6	64	7	68	8	49	4	73	13	73	68	491	4.25	30.69
1885	18,000	11	107	17	82	8	76	8	60	9	42	174	687	9.67	38.17
1886	18,000	14	45	10	44	7	41	11	34	11	53	291	497	15.61	27.61
1887	18,000	21	71	13	41	19	48	19	42	8	42	259	481	14.39	26.72
1888	18,000	9	25	7	49	7	32	7	63	6	54	82	448	4.55	24.88
1889	17,000	1	20	0	10	0	18	0	13	0	15	33	249	1.83	13.83
1890	16,000	0	22	0	23	0	18	0	12	0	12	0	198	0	12.37
1891	16,000	3	10	3	18	0	9	0	17	0	7	17	178	1.06	11.12
1892	16,000	0	14	0	11	0	7	0	5	0	9	1	133	.06	8.31
1893	16,000	0	14	0	18	0	14	0	10	0	12	1	142	.06	8.87
1894	16,000	0	21	0	14	0	12	0	6	0	12	0	137	0	8.56
1895	16,000	0	10	0	15	0	9	0	16	0	17	0	138	0	8.62
1896	17,000	0	10	0	13	0	6	0	22	0	12	0	168	0	10.50
1897	17,000	1	24	1	10	0	11	0	12	0	15	45	203	2.81	11.95
1898	17,000	0	25	0	11	0	10	0	8	0	13	0	161	0	9.50
1899	17,000	17	16	12	21	1	26	2	16	9	12	87	190	5.12	11.18
1900	17,000	29	28	5	12	0	16	2	13	2	16	109	187	6.41	11.00
1901	17,000	0	11	0	22	0	15	0	12	0	16	5	134	.29	7.88
1902	19,000	36	55	14	58	41	110	32	56	20	47	202	562	10.63	29.58
1903	18,000	11	14	3	8	1	16	0	18	0	13	51	178	2.78	9.89
1904	18,000	0	7	1	8	0	17	0	15	0	16	8	162	.95	9.00
1905	20,000	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	22	41	[a]1.89	[a]3.51
Total	.....	161	613	93	556	92	560	88	541	84	525	1,454	5,800		

[a] Other months estimated at same rate.

NOTE.—Data respecting mortality supplied by Col. W. C. Gorgas, U. S. Army, chief sanitary officer, Panama Canal, who obtained the same from the original records of the Panama cemeteries; there were no burials elsewhere. These official records were found well kept, the cemetery sexton being required by local law to file the death certificates of physicians, wherein are stated individually the name, age, sex, nativity, and cause of death in every case. Above data relate only to malaria and yellow fever. The population of Panama is given as the nearest approximation obtainable. The figure for 1905 is official, and resulted from a house to house census under direction of the chief sanitary officer.

WASHINGTON, D. C., *November, 1905.*

465A—06——36

Appendix P.

TRANSFORMATION OF A LOCK CANAL INTO A SEA-LEVEL CANAL.

Report of the Committee on Lock-Canal.

The Lock-Canal Committee, in accordance with requests made at the meeting of the Board held on Tuesday, November 7, herewith respectfully submits a report upon the practicability and cost of developing a sea-level canal from a lock canal.

It had before it the resolution upon this subject adopted by the Board at its sixth meeting, which is as follows:

Resolved, That it is desirable that studies shall be made of the practicability of developing a sea-level canal from any project which primarily involves a lock canal.

It had also before it the remarks of the President of the United States upon this subject, dated September 11, 1905, which are as follows:

I desire also to know whether, if you recommend a high-level multilock canal, it will be possible after it is completed to turn it into, or to substitute for it, in time, a sea-level canal, without interrupting the traffic upon it.

Our studies of this subject led us to the conclusion that the President's request may be answered in the affirmative, as we believe it to be possible to turn a lock canal into a sea-level canal without interrupting the traffic upon it. In order to do the work in an economical manner, however, it might be advisable to use methods which would sometimes delay ships passing through the canal.

The committee does not regard the depression of a lock canal to sea level as an easy task or one for which a trustworthy estimate of cost could be made at the present time. It evidently involves the excavation of immense quantities of rock and earth, much of it at depths considerably exceeding 40 feet below the surface of the water. The Board, having in view the removal of rock at depths less than 40 feet, has adopted as the price for excavating rock under water $2.50 per cubic yard, while for rock excavated "in the dry" it has adopted $1 and $1.15 per cubic yard, except in the Culebra cut, where for all classes of materials above elevation +10 a price of 80 cents per cubic yard, and for all classes of materials below elevation +10 a price of $1.25 per cubic yard has been adopted. For the dredging of earth from the canal a price of 25 cents per cubic yard was adopted as against 40 cents per cubic yard for earth in the dry.

As rock is the predominating material to be excavated in depressing the canal from a lock level, it is obvious from the unit prices adopted that a sea-level canal obtained by first building a lock canal would cost very much more than a sea-level canal constructed by a direct process, and we believe that if a sea-level canal is necessary in the near future it should be built directly without first building a lock canal.

If the transformation should be delayed until the traffic became very great, the committee believes a wider channel than that proposed by the Sea-Level Canal Committee would be required, and accordingly submits two estimates of the cost of such transformation, one to a

bottom width of 150 feet (200 feet through Culebra cut), the other to a bottom width of 300 feet throughout:

Estimate of quantities and of cost of transforming a lock canal with summit elevation 85 to a sea-level canal with cross sections provided by the Sea-Level Canal Committee.

EXCAVATION.	Earth. Cubic yards.	Rock. Cubic yards.
Excavation for sea-level canal from Gatun dam, kilometer 8, to Obispo, kilometer 46	68,500,000	13,900,000
Deduct material to be excavated for canal with summit elevation 85, say	4,000,000	500,000
To be excavated for transforming canal	64,500,000	13,400,000
Culebra section, kilometer 46 to kilometer 59:		
Total excavation, sea-level canal		110,000,000
Deduct portion excavated for canal with summit elevation 85		54,000,000
To be excavated for transforming canal		56,000,000
In order to apply the unit prices this quantity has to be subdivided as follows:		
Portion above water		14,200,000
Portion not more than 25 feet below water surface		6,500,000
Portion more than 25 feet below water surface		35,300,000
Total		56,000,000

COST.	
64,500,000 cubic yards earth, kilometer 8 to kilometer 46, at 25 cents	$16,125,000
13,400,000 cubic yards rock under water, kilometer 8 to kilometer 46, at $2.50	33,500,000
14,200,000 cubic yards excavation above water in Culebra section, at 80 cents	11,360,000
6,500,000 cubic yards rock excavation in Culebra section from surface of water to 25 feet below, at $1.50	9,750,000
35,300,000 cubic yards rock excavation in Culebra section more than 25 feet below water surface, at $2.50	88,250,000
Total	158,985,000
Add for dams and diversion channels and for transforming section of canal between Pedro Miguel and Miraflores, say	25,000,000
Add for removing the locks at Gatun and Pedro Miguel, for modifying the lock at Miraflores, and for removing the regulating works at the Gatun dam and at Miraflores, say	25,000,000
Total cost of transforming lock canal to sea level on basis of canal sections of Sea-Level Canal Committee	208,985,000

Estimate of quantities and of cost of transforming lock canal with summit elevation 85 to sea-level canal with bottom width of 300 feet.

EXCAVATION.	Earth. Cubic yards.	Rock. Cubic yards.
Excavation for sea-level canal from Gatun dam to Obispo, say 70 per cent in excess of Sea-Level Canal Committee's quantities	116,500,000	23,600,000
Deduct portion excavated for canal with summit elevation 85, say	5,500,000	700,000
To be excavated for transforming canal	111,000,000	22,900,000
Culebra section, kilometer 46 to kilometer 59:		
Total excavation for sea-level canal		162,000,000
Deduct portion excavated for canal with summit elevation 85		54,000,000
To be excavated for transforming canal		108,000,000
Subdivision of last-named quantity:		
Portion above water		46,400,000
Portion not more than 25 feet below water surface		10,500,000
Portion more than 25 feet below water surface		51,100,000
Total		108,000,000

COST.

110,000,000 cubic yards earth, kilometer 8 to kilometer 46, at 25 cents	$27,750,000
22,900,000 cubic yards rock under water, kilometer 8 to kilometer 46, at $2.50	57,250,000
46,400,000 cubic yards excavation above water in Culebra section, at 80 cents	37,120,000
10,500,000 cubic yards rock excavation in Culebra section from surface of water to 25 feet below, at $1.50	15,750,000
51,100,000 cubic yards rock excavation in Culebra section more than 25 feet below water surface, at $2.50	127,750,000
Total	265,620,000
Add for dams and diversion channels and for transforming section of canal between Pedro Miguel and Miraflores, say	26,000,000
Add for removing the locks at Gatun and Pedro Miguel, for modifying the lock at Miraflores, and for removing the regulating works at Gatun dam and at Miraflores, say	25,000,000
Total cost of transforming lock canal into sea-level canal having a bottom width of 300 feet	316,620,000

SUMMARY.

The committee is of the opinion:

1. That it is possible to turn any lock canal which it has considered into a sea-level canal without interrupting the traffic upon it.

2. That it is practicable from an engineering standpoint to transform any lock canal which it has considered into a sea-level canal, but that the cost of such transformation is so great as to render such a change impracticable from a financial standpoint, until the traffic should have so increased as to tax the capacity of the lock canal, or until other good and sufficient reasons existed for such a change.

3. If a sea-level canal is to be constructed in the near future it should be built directly without first building a lock canal.

4. That the date for developing a sea-level from an existing lock canal would be so remote, and there is so little difference in the time and cost of the transformation from different types of lock canals with a common summit level, that the design of a lock canal should not be controlled by the view that it is subsequently to be so transformed.

5. That the cost of developing a lock canal with summit elevation of 85 into a sea-level canal of the sections reported by the Sea-Level Canal Committee is, with the prices adopted by the Board, $246,270,000, and of developing into a sea-level canal with a bottom width of 300 feet $355,875,000. These sums have not been increased by the usual addition of 20 per cent for contingencies, etc.

6. That the committee is unable to express any definite opinion as to the time required to effect such a transformation to a sea-level canal.

It is believed that in the future, methods and appliances for the work required for depressing the canal will be improved to such an extent as to greatly diminish the cost and time of the transformation.

Appendix Q.

HISTORICAL SKETCH OF THE PANAMA CANAL.

By Alfred Noble.

The establishment of a commercial route across the American Isthmus occurred in the early part of the sixteenth century. The settlement of old Panama was made in 1517, and soon afterwards it became the Pacific terminus of a trade route between Panama and Nombre de Dios, on the Atlantic coast, which lay to the eastward of the line of the present Panama Railroad, crossing the Chagres at Las Cruces. Traces of this road are still to be seen. In 1597 the Atlantic terminus was changed to Porto Bello, where the climate was better and the harbor excellent. The route became a most important one. Gold and silver from the mines of Peru were carried across it, and it became the principal channel of communication between Spain and her colonies on the Pacific coast of the continent and even with the Spanish possessions in the Far East.

The idea of forming a communication by water from the Atlantic to the Pacific was advanced at a very early day. It is said that a survey of the Isthmus of Panama with this object was ordered by Charles V in 1520. In 1534 it was directed by royal decree that the region between the Chagres and the Pacific be surveyed and the most convenient means ascertained for effecting a communication between the Chagres and the Pacific. The governor of the province reported that such a work was impracticable. With the abdication of Charles V in 1555 and the succession of Philip II, who reigned until 1598, the policy was changed; the project for a canal across the Isthmus was no longer prosecuted, and this continued for two centuries after his death. Although the idea was attractive and much discussed, no further steps are known to have been taken for establishing a water communication across the Isthmus of Panama until about the opening of the nineteenth century. The successful revolt of the Spanish provinces, from 1819 to 1823, terminated the efforts of Spain in its behalf.

In 1827 Mr. J. A. Lloyd was commissioned by President Bolivar to survey the Isthmus and ascertain the most feasible route across it, either for road or canal. He spent two seasons in the country, carried the first line of levels across it, and recommended a new line across the Isthmus instead of the two then in use, which were from the mouth of the Chagres and from Porto Bello, respectively, to Las Cruces and Panama. The new route was to be by canal from the bay of Limon to the Chagres and by that stream to a favorable point on the south bank of the Trinidad, and thence by rail to Panama or Chorrera. He did not advocate a canal across the Isthmus, but said the Trinidad would probably offer the most favorable route.

Upon the division of the Republic of Colombia, in 1831, the Isthmus of Panama passed under the control of New Granada. In 1838 a concession was granted to a French company for the construction of macadamized roads, railroads, or canals across the Isthmus to Panama as the Pacific terminus. Several years were spent in explorations and in attempts to interest the Government of France in the enterprise. It was stated that the summit of the pass across the divide was only 37 feet above mean sea level at Panama. This statement was so surprising, and if true so important, that in September, 1843, Monsieur Guizot, then minister of foreign affairs, instructed Napoleon Garella to proceed to Panama, investigate the question, and report upon it.

Garella advocated a canal as the only adequate means of communication across the Isthmus. Adopting Lloyd's suggestion, he favored the bay of Limon as the Atlantic terminus, his line reaching the Chagres a little below the mouth of the Gatun. No such low depression across the divide as had been reported could be found, and he reported two projects, one for crossing by a tunnel under the divide, the other by a deep, open cut. The summit level of the canal, in the tunnel project, was to be 158 feet above extreme high tide in Panama Bay, and was to be reached by 18 locks on the Atlantic side and 16 on the Pacific side, and supplied with water from the Chagres through lateral canals. The Pacific terminus was to be at Vaca de Monte, about 12 miles southwest of Panama. The estimated cost was about $25,000,000. In the open-cut project the summit cut was to be 275 feet deep and the water level in it about 50 feet higher than in the tunnel canal. The estimated cost of building this project was about $28,000,000. The canal in either case was to be 23 feet deep and accommodate vessels 198 feet long, 45 feet beam, and 21 feet draft. This report was disappointing to the holders of the concession, which was allowed to lapse. With the discovery of gold in California in 1848 the Panama crossing, following the Chagres to Las Cruces and the old Spanish road to Panama, became immediately one of the principal links of communication between the Eastern States and the mining regions. A treaty had already been negotiated between the United States and the Republic of New Granada and concluded in December, 1846, securing the right of transit across the Isthmus of Panama, although ratifications were not exchanged until June, 1848. In May, 1847, while ratifications were pending, the Republic granted to the Panama Company, a French company represented by Mateo Kline, the exclusive privilege for ninety-nine years of building a railroad across the Isthmus, but this company failed to carry out its obligations and the concession was declared forfeited. Subsequently, in December, 1848, the concession, with some modifications, was renewed in favor of Messrs. Aspinwall, Stephens, and Chauncey, who, with their associates, under the name of the Panama Railroad Company, built the railroad from Aspinwall, or Colon, to Panama, and opened it for traffic early in 1855. Subsequently modifications of the concession were made, and in its modified form the Republic agreed to grant no privilege during the term of ninety-nine years from August 16, 1867, to any other company or person to open any other railroad or any maritime canal to the west of a line drawn from Cape Irburon, on the Atlantic coast, to Cape Garachine, on the Pacific; nor to establish any such communication itself. This gave the railroad company exclusive control of the Panama route.

The railroad, however, did not fully meet the necessity for better communication between the oceans, and the demand for a waterway at some point remained unabated. In 1869, in his first message to Congress as President, General Grant took strong ground in its favor, and Congress immediately authorized surveys across the American Isthmus at several localities. In March, 1872, in pursuance of another act of Congress the work was placed under the direction of a commission consisting of Gen. A. A. Humphreys, Chief of Engineers, U. S. Army; C. P. Patterson, Superintendent of the Coast and Geodetic Survey, and Commodore Daniel Ammen, Chief of the Bureau of Navigation of the United States Navy. The survey of the Panama route was placed under the charge of Capt. Edward P. Lull, U. S. Navy, and was made in 1875. He reported in favor of a line which followed the general direction of the Panama Railroad from the bay of Limon to Chagres, thence up this stream and the Obispo to the divide, thence by the valley of the Rio Grande to Corozal, and thence to the Pacific west of the city of Panama. This line, with some modifications, has been followed subsequently.

In May, 1876, Lieut. L. N. B. Wyse, as the representative of a French company, entered into a contract with the Colombian Government which, as modified and extended two years later, gave him and his associates the exclusive privilege for ninety-nine years of constructing and operating a canal between the oceans anywhere in the Republic; providing, however, that if such canal should be located within the territory covered by the concession to the Panama Railroad Company an amicable arrangement should be made with that company.

In accordance with the provisions of the Wyse contract, an "International Scientific Congress" was convened at Paris in May, 1879, to determine upon the general route of the proposed canal, and it was decided that the best route was from the bay of Limon to the bay of Panama.

The contract or concession was subsequently transferred to the Compagnie Universelle du Canal Interoceanique du Panama, chartered under the laws of France, and Ferdinand de Lesseps became its leading spirit. The condition imposed in the concession, that an amicable arrangement should be made with the Panama Railroad Company, was met by the purchase of a controlling amount of the stock of the railroad company. The work of constructing the canal was then taken up and a vast amount of money expended, but in December, 1888, the effort was given up. In February, 1889, a liquidator or receiver was appointed and authority given to transfer the assets of the company to any new company. These delays made extensions of time necessary, which were successively granted in 1890, 1893, and finally in 1900; under the last extension the time for completing the canal was fixed at October 31, 1910.

In October, 1894, a new company, under the name of the New Panama Canal Company, was organized under the laws of France, in which the receiver of the old company was a party. Under this organization work was resumed on the canal on a moderate scale, consisting mainly of the care of the plant and other property accumulated by the old company and the prosecution of excavation at the Culebra cut. The latter was chiefly important as giving valuable information respecting the character of the materials in the cut and the cost of removing them. Other investigations bearing upon all questions affecting the construction of the canal were taken up and pursued with great thoroughness.

In 1899 steps were taken by the United States looking toward the acquirement of the right to build a canal across the Isthmus of Panama. A commission was appointed to consider the whole question of Isthmian transit, including the cost of purchasing all the rights, privileges, and franchises held and owned by corporations, associations, and individuals in the different canal routes. The commission reported January 18, 1902, in favor of the Panama route.

The data which form the basis of the foregoing are found in the report of the Isthmian Canal Commission of 1899–1901.

The act of Congress approved June 28, 1902, authorized the President to acquire, at a cost not exceeding $40,000,000, the rights, franchises, and property of every kind belonging to the New Panama Canal Company, including its shares of the Panama Railroad Company, provided a satisfactory title could be obtained. The President was also authorized to acquire from the Republic of Colombia, upon such terms as he might deem reasonable, perpetual control of a strip of land not less than 6 miles in width across the Isthmus of Panama, and to construct and perpetually maintain, operate, and perfect a canal from the Caribbean Sea to the Pacific Ocean, which control should include the right to perpetually maintain and operate the Panama Railroad, provided the United States should acquire a controlling interest therein.

The act also directed the President to cause to be constructed a ship canal from the Caribbean Sea to the Pacific Ocean "of sufficient capacity and depth as shall afford convenient passage for vessels of the largest tonnage and greatest draft now in use, and such as may be reasonably anticipated" with all necessary locks and other appliances, as well as safe and commodious harbors at the termini, and suitable provisions for defense.

The sum of $10,000,000 was appropriated, and the President directed to cause contracts to be entered into for the construction of the canal, its harbors and defenses, limiting the expenditure to the additional sum of $135,000,000, to be met by future appropriations, and the Secretary of the Treasury was authorized to borrow a sum not exceeding $130,000,000 on bonds bearing interest at the rate of 2 per cent per annum. The act finally created the Isthmian Canal Commission, to be composed of seven members. Owing to various delays the Commission was not appointed until 1904. In the meantime a treaty had been negotiated by Mr. Hay, Secretary of State, and Mr. Herran, representing the Government of Colombia, to empower the United States to construct the canal. This treaty was ratified by the United States, but rejected August 12, 1903, by the Colombian Congress. Discontent in the Department of Panama over the rejection of the treaty ripened into revolt on the 3d of November, and independence was declared. A government was organized immediately and recognized by the United States. The Republic of Panama designated Mr. Philippe Bunau-Varilla as its envoy extraordinary and minister plenipotentiary to the United States, and a treaty, known as the Hay-

Bunau-Varilla treaty, was negotiated, ratified by the Republic of Panama December 2, 1903, and by the United States February 23, 1904. By this treaty the United States is granted in perpetuity the use, occupation, and control of a zone of land and land under water for the construction, maintenance, operation, sanitation, and protection of a canal, the zone extending 5 miles on each side of the line of the canal. The like control and use is also granted of any other lands and waters outside the zone which may be necessary and convenient for the work. It was provided that the Republic of Panama should receive the sum of $10,000,000 for the rights, powers, and privileges granted by the treaty, and also an annual payment of $250,000 beginning after nine years.

On April 23, 1904, the stockholders of the New Panama Canal Company formally authorized the sale of the company's property to the United States upon the payment to the company of the sum of $40,000,000. The transfer of property on the Isthmus was made May 4, 1904, the United States being represented by Lieut. Mark Brooke, Corps of Engineers, U. S. Army.

In the meantime the Isthmian Canal Commission created by the Spooner Act had been appointed, and held its first meeting March 22, 1904. Its members were Rear-Admiral John G. Walker, U. S. Navy (retired), chairman; Maj. Gen. George W. Davis, U. S. Army (retired); Mr. Wm. Barclay Parsons, C. E.; Mr. William H. Burr, C. E.; Mr. Benjamin M. Harrod, C. E.; Mr. C. Ewald Grunsky, C. E., and Col. Frank J. Hecker. On May 6, Mr. John F. Wallace was appointed chief engineer, and assumed his duties June 1.

On May 9 the President, through the Secretary of War, placed the Commission in charge of the government of the Canal Zone, giving it the power to legislate, and appointed Maj. Gen. George W. Davis, governor.

When the ultimate transfer of its property to the United States became assured, the French company reduced its force on the Isthmus so that, at the time of the transfer, the total of all employees numbered only about 700. The Commission decided to continue the work then in progress and to increase the force gradually, for the purpose, mainly, of gathering further data regarding the cost of excavation, and also to make further and extensive surveys and investigations of various kinds with a view to more reliable estimates and better solutions, if found possible, of the problems of the work. The sanitation of the Isthmus, justly regarded as of primary importance, was also taken in hand and placed under the direct charge of Col. William C. Gorgas, of the Medical Department, U. S. Army, whose successful work in a similar position during the American occupation of Habana is well known. Colonel Gorgas assumed his duties in July, 1904.

Col. Frank J. Hecker resigned November 16, 1904, and all other members of the Commission resigned to take effect at the pleasure of the President. A new Commission, composed of Mr. T. P. Shonts, chairman; Mr. Charles E. Magoon, governor of the Canal Zone; Mr. John F. Wallace, chief engineer; Rear-Admiral M. T. Endicott, U. S. Navy, Chief of Bureau of Yards and Docks; Brig. Gen. Peter C. Hains, U. S. Army (retired); Col. O. H. Ernst, Corps of Engineers, U. S. Army, and Mr. Benjamin M. Harrod, C. E., was appointed and entered upon its duties April 1, 1905, the date on which the resignations of the former Commissioners were accepted. Mr. Wallace resigned June 13, 1905, and the vacancy in the Commission thus created has not been filled. He was succeeded as chief engineer by Mr. John F. Stevens, C. E., who was appointed July 1, 1905, and entered upon his duties immediately.

The work done and results obtained since the occupation by the United States are described in more detail elsewhere in the report.

Appendix R.

UNIT PRICES.

Report by the Committee on Unit Prices.

Washington, D. C., *October 30, 1905.*

Sir: The Committee on Unit Prices begs leave to submit the attached schedule of prices to be used in making preliminary estimates.

The chief engineer of the Isthmian Canal Commission declined, when a witness before the Board, to venture any statements as to the probable cost, as the data were not on hand on which to base a reliable opinion as to estimates. The committee appreciates this lack of information, and in suggesting prices does so with the view that they be made general approximations to cover all contingencies in variations in design, execution of the work, and accidents.

In the application of these prices some inconsistencies will become apparent, in that a cost price is not always uniform. It must be remembered that any estimated price is necessarily only approximate, and should be made high enough to guard against errors, and will then be high enough to cover small variations from average conditions. It is recommended that the prices be used broadly.

Very respectfully,

Wm. Barclay Parsons,
Isham Randolph,
J. W. Welcker,
Committee on Unit Prices.

Gen. Geo. W. Davis,
Chairman Board of Consulting Engineers,
Isthmian Canal Commission.

PANAMA CANAL—SCHEDULE OF UNIT PRICES.

EXCAVATION.

		Price.
Earth:		
Earth in dry, except in Culebra	cubic yard	$0.40
Rock:		
Soft rock in dry, except in Culebra	do	1.00
Hard rock in dry, except in Culebra	do	1.15
Hard rock in lock pits, below elevation −10	do	1.50
Dredging:		
Mud and sand in Colon and Panama harbors	do	.15
Soft material removed by hydraulic pumps, in canal	do	.25
Indurated and hard clay requiring cutters	do	.70
Coral rock	do	1.50
Rock drilled and blasted in the dry, to elevation −25, removed by dredge	do	1.50
Rock removed under water	do	2.50
Culebra cut:		
All material, without classification, above elevation +10	do	.80
All material below elevation +10	do	1.25

		Price.
Dams:		
Earth borrowed	cubic yards	$0.50
Extra price for placing in dams, regardless of classification, from line of canal within a distance of 4 miles	cubic yard	.20
Extra price for placing in dams, regardless of classification, from line of canal over 4 miles	cubic yard	.25
When placed in dam by pump, from barges, below elevation +50	do	.20
When placed in dam by pump, from barges, above elevation +50	do	.30
Railroad excavation:		
Earth	do	.40
Rock	do	1.00
Track, including rails, ties, ballast, etc	mile	10,000.00
Masonry:		
Concrete	cubic yard	8.00
Granite, cut quoins, and miter walls	cubic foot	3.00
For copings	do	2.00
Brick lining for culverts	cubic yard	15.00
Timber:		
In miter sills	1,000 feet	100.00
In permanent cribs	do	55.00
Foundation piles, creosoted	linear foot	.55
Iron:		
Structural steel	pound	.075
Cast iron for culverts, miter sills, including machinery	do	.04
Stoney sluices, 30 feet opening, 15 feet high	each	15,000.00
Stoney sluices, 50 feet opening, 15 feet high	do	25,000.00
Gamboa or other dam excavation, earth in foundation, including cofferdam, temporary dam, and pumping:		
If stream is not diverted	cubic yard	2.50
If stream is diverted	do	1.00
Rock in foundation—		
If stream is not diverted	do	2.50
If stream is diverted	do	1.50
Diversion channel:		
Earth	do	.40
Rock	do	1.00

Appendix S.

ARTIFICIAL WATERWAYS, THEIR IMPROVEMENT AND NAVIGATION.

By Joseph Ripley.

Improvement.—Throughout the United States, along the seacoast, on the Great Lakes, in the principal rivers, where natural waterways have been improved or artificial channels constructed for purposes of navigation, the insistent demand has been for deeper, wider, and straighter channels. All these particulars are notably exemplified in the new entrance channel to New York Harbor. A minimum channel width of 1,000 feet is the present standard which all the important ocean ports are striving to secure. The numerous lake ports, such as Duluth, Marquette, Chicago, Cleveland, and Buffalo, which have their deepened and enlarged harbors provided with entrance piers or protected by extensive breakwaters, form one part of the important improvements made by the United States Government to protect and facilitate the safe movement of lake commerce.

These demands have also been exemplified in the connecting rivers between the Great Lakes. On completion of the canal around St. Marys Falls in 1855, with about 12 feet of water on the miter sills, the available draft through the St. Marys River was 8 feet. During the next three years the shoals were deepened to 12 feet, and widths of 150 to 250 feet were considered ample for the dredged channels. By 1870 the importance of the lake commerce warranted enlargement of the channel ways, but a decade passed before the depth of 16 feet and widths of 250 to 300 feet had been secured, together with enlarged lockage capacity. To provide for night navigation of the river, the shorter and comparatively straight channel through Hay Lake and the Middle Neebish, with depth of 20 feet and minimum width of 300 feet, was opened to navigation in 1894, and the tortuous channel by the way of Lake George was practically abandoned. The Canadian lock in 1895 and the Poe lock in 1896 correspondingly increased the lockage facilities. On completion (in the near future) of the West Neebish channel, the deepening of the Middle Neebish, and the building of a new lock, the St. Marys River will have a navigable depth of 21 feet at extreme low water, with least width of 300 feet where traversed by vessels moving in the same direction and widths of 600 to 1,500 feet where common to ships passing in both directions.

Navigation of the natural channel through the St. Clair River was restricted by the sand flats at the mouth of the river to 10 feet draft. A canal about 1.5 miles long and 300 feet wide between two parallel timber piers was finished across the flats in 1871. The respective deepenings to 16, 18, and 20 feet duly followed. In 1895 the channel across Lake St. Clair was made 800 feet wide and the one through the shoals at the foot of Lake Huron 1,500 feet wide. At present a canal 300 feet wide and 21 feet deep is being built adjacent to and parallel to the first one.

A ridge of limestone extending across the mouth of the Detroit River limited the draft to 13 feet at first. In 1874 a channel 19 feet deep and 250 feet in general width, but widening at approach ends to 400 feet, was commenced, the curve being made to coincide with the direction of the current. The first change was for uniform width of 440 feet, and finally the curvature was eliminated and a straight channel made 600 feet wide and 22 feet deep.

In accordance with an act of Congress estimates of cost are about to be submitted for deepening the channels of these rivers to 25 feet. Similarly the channels of the Mississippi and its tributary rivers have been progressively improved. The Erie Canal is being enlarged at an expense of over $100,000,000. Many of the foreign harbors and canals are passing through like stages of improvement.

Navigation.—Careful observation of lake navigation has fully shown that a waterway of considerable length to be easily and safely navigated at a fair rate of speed must have a prism of such dimensions that it will afford good steerage way. Preferably each course should be straight, with

ample widening at the angles between the adjacent courses and with the depth 1 to 5 feet greater than the still draft, depending on the size and allowable speed of ships. For widths less than 300 feet smooth, vertical sides should be provided for the greater safety of ships, while for widths of 500 feet or more submerged channels can have side slopes such as the material will naturally assume or as will be left by the excavating machine.

Among the advantages of the straight alignment over the curved courses mention is made of the possibility of erecting center-line ranges for both day and night beacons; the knowledge as to definite position in channel of approaching ships; greater ease in handling ships with less liability to sheer; and the incorrect position of displaced buoys can be more readily noticed and groundings possibly avoided.

The instrumental determination of the movement of ships in turning a deflection angle of 65° between courses in the St. Marys River showed that generally no checking was made from the allowable speed of 9 miles per hour except in case of three new ships— *Wallace*, *White*, and *Corey*—when making their first or second trip; that for most of the ships the radius of curvature of the first and last part of turn was three to six times the length of the ship, and of the general curvature of the entire turn was three and one-half to ten times the length. Ships 569 feet long were among those making the sharpest turns.

Curvature made by ships in turning the angle at head of Little Mud Lake.

[From instrumental observations.]

Ship.	Length of ship over all.	Radius of curvature.				Direction.
		Ends of turn.	Ratio of radius to length of ship.	Entire turn.	Ratio of radius to length of ship.	
	Feet.	*Feet.*		*Feet.*		
H. W. Smith	434	1,850	4.2	2,200	5.0	Upstream.
R. W. England	382	2,150	5.6	2,320	6.1	Do.
Wisconsin	464	2,100	4.5	2,500	5.4	Do.
Zenith City	405	1,800	4.4	2,000	4.9	Do.
G. W. Perkins	569	1,860	3.2	1,920	3.4	Do.
Samuel Mitchell	308	1,900	6.0	2,500	8.1	Do.
India	222	1,700	7.6	1,900	8.5	Do.
Bramford	435	2,100	4.8	3,650	8.4	Do.
Yuma	340	2,550	8.0	3,550	10.4	Do.
Sylvania	524	2,100	4.0	2,600	5.0	Downstream.
E. H. Gary	569	2,200	3.9	2,600	4.5	Do.
Peter White	525	2,250	4.2	3,100	6.0	Do.
Samuel Mitchell	308	1,800	6.0	3,000	9.9	Do.
Athabasca	270	1,900	7.0	2,250	8.4	Do.
Northern King	315	1,900	6.0	3,750	12.0	Do.
Princeton	474	1,600	3.4	2,500	5.3	Do.
Maunaloa	450	2,260	5.0	3,030	6.7	Do.
Roman	313	1,900	6.0	2,300	7.3	Do.
H. S. Sill	436	1,800	4.1	4,120	9.4	Do.
John Crerar	257	1,850	7.2	3,240	12.6	Do.
John C. Wallace	552	2,000	3.6	3,000	5.4	Do.
Wm. E. Corey	569	2,000	3.5	3,200	5.8	Do.

Delays.—The delays at locks and those occurring in the improved channels of canals and canalized rivers and lakes between the Great Lakes and St. Marys Falls Canal have been observed and recorded. The State locks, two tandem, were in operation 32 years, and for 26 years formed the only passageway for the entire Lake Superior commerce. The superintendents report a break in the canal embankment in 1857, necessitating the closing of the canal for 60 hours. In 1865 and 1866 a diver was employed to stop leaks under miter sill platform of upper gates, and again in 1874 for leak under floor of lower gates. In 1873 the miter sill of middle gates rose 6 inches, but no mention was made as to time taken for repairs, or as to there being any actual delay to vessels. The records, however, are not complete for the period 1855 to 1880. Since control of the canals was taken over by the National Government in 1881, full record has been kept of the actual delays to navigation on account of breakages, etc, and they are listed as follows:

Delays to navigation on account of breakages, etc., Weitzel and Poe locks.

	Weitzel lock, 1881–1905.	Poe lock, 1896–1905.
	Hours.	*Hours.*
Gate engines	0	282
Gate cables	309	145
Sheaves for cables	3	44
Obstructions against miter sills	55	37
Grounding on platforms	194	26
Fouling of tow lines	60	26
Jamming of vessels	23	12
Gates	373	204
Pressure pipes	125	48
Gratings	33	6
Valves in culverts	88	0
Substitution of oil for water in pressure system	404	249
Miscellaneous	31	25
Total	1,698	1,104

The Weitzel lock was for 8½ years the only one connecting Lake Superior with the lower lakes. The total delay of 71 days during 25 years makes an annual average of 3 days, of which 1½ days were due to failure of lock machinery. The longest delay was one of 88 hours, due to broken trunnion on one of the valves, and it affected nearly all of the Lake Superior traffic, no other lock being in use at that time. The Poe lock has a total delay of 46 days in 10 years, or an annual average of 4½ days. The longest delay, of 170 hours while making temporary repairs to lower gates damaged by an upbound boat, did not seriously inconvenience navigation, as both the Weitzel and the Canadian locks were in operation. The average delay for the past 4 years has been only one-half day per annum due to breakage of machinery, including damages to gates.

Generally the delays have affected only a few vessels, and in many cases only one. Necessary repairs to locks and machinery have been made every winter. The longest delay at the canal lasted five days and had nothing to do with the locks, but was caused by the displacement of the railroad swing bridge across the canal. This stopped navigation through the United States canal only, the Canadian canal being used.

Navigation through the river channels was not restricted as to speed of vessels until 1896. At present the regulations limit the speed to 9 miles per hour, and require meeting steamers to slow to half speed within one-fourth mile of each other. The general practice had been to run at 10 to 15 miles per hour, and the groundings and collisions were so frequent that the loss to the insurance companies amounted to $400,000 in one season, and the indirect damages caused by delays were much larger. In 1904 there were 34 groundings—principally during foggy weather—21 were released with the assistance of a tug, and 13 had to be lightered 300 to 1,000 tons each. In 1905 the number of accidents was about one-third less.

Every year the grounding of ships on the channel banks or sinking in the channel as a result of collisions has temporarily interfered with navigation. Since 1891 there have been three complete blockades of Lake Superior commerce by sunken vessels in river channels, each one of them lasting five days. The loss to navigation interests was carefully determined for each case and totaled for the three $900,000, which amount exceeds the losses due to the extra delays at the locks during the past fifty years.

The St. Clair Flats Canal, 1½ miles long, without locks, and with a speed limit of 8 miles per hour, has been the scene of many blockades, and the resultant delays to navigation have greatly exceeded those at St. Marys Falls Canal.

The results show that a larger number of accidents with more serious outcome take place in the narrower channels under the same regulations as to speed than occur in the wide channels, where both are used for vessels moving in both directions. These narrower channels are, however, of about double the width which would be provided in the greater part of the sea-level canal.

Appendix T.

ESTIMATES OF COST OF LOCK CANAL.

[Supplemental to the minority report.]

Breakwaters in Limon Bay (length 4½ miles), from mile 0 to mile 3.30, using the estimate adopted by the Board		$5,000,000
Extension of breakwater, 1¼ miles in length, from mile 3.30 to head of Limon Bay (mile 4.55), 400,000 cubic yards, at 75 cents		300,000
Excavation of channel in Limon Bay, 40 feet in depth below low water and 500 feet wide, from mile 0 to mile 4.55:		
Earth (dredging), 8,300,000 cubic yards, at 15 cents		1,245,000
Excavation 40 feet in depth below low water and 500 feet wide from head of Limon Bay (mile 4.55) to northerly end of Gatun locks (mile 7.15):		
Earth (dredging), 10,000,000 cubic yards, at 25 cents	$2,500,000	
Indurated clay (dredging), 2,030,000 cubic yards, at 70 cents	1,421,000	
		3,921,000
Excavation for Gatun locks, mile 7.15 to mile 7.74:		
Earth, 920,000 cubic yards, at 40 cents	368,000	
Indurated clay, 2,740,000 cubic yards, at 70 cents	1,918,000	
		2,286,000
Gatun locks exclusive of excavation and approach walls		13,075,000
Approach walls of Gatun locks		500,000
Backfilling and embankment, Gatun locks, 660,000 cubic yards of borrowed earth, at 50 cents		330,000
Gatun dam:		
Earth embankment—		
Below elevation 50, 12,170,000 cubic yards of dredged material pumped into dam, at 20 cents	$2,434,000	
Between elevation 50 and elevation 80, 5,770,000 cubic yards of dredged material pumped into dam, at 30 cents	1,731,000	
Above elevation 80, 3,260,000 cubic yards of material from excavations placed in dam, at 25 cents	815,000	
Excavation for diversion channel and regulating works—		
Earth, 1,100,000 cubic yards, at 40 cents	440,000	
Indurated clay, 480,000 cubic yards, at 70 cents	336,000	
Concrete in regulating works and for protection of diversion channel, 189,000 cubic yards, at $8	1,512,000	
Regulating gates and machinery (complete)	320,000	
Allowance for preparatory work at site of Gatun dam and miscellaneous expenses	200,000	
Total for Gatun dam		7,788,000
Excavation from Gatun locks (mile 7.74) to Obispo (mile 31.25), making channel 45 feet deep and not less than 500 feet wide for 23.51 miles, of which 15.92 miles is not less than 1,000 feet wide:		
Earth excavation in the dry, 600,000 cubic yards, at 40 cents	$240,000	
Indurated clay excavation at Gatun, 130,000 cubic yards, at 70 cents	91,000	
Earth excavation (dredging), 12,960,000 cubic yards, at 25 cents	3,240,000	
Rock excavation in the dry, 1,160,000 cubic yards, at $1.15	1,334,000	
		4,905,000
Cutting trees in Gatun Lake		100,000
Excavation from mile 31.25 to mile 32.80, channel 45 feet deep and 300 feet wide, with slopes of 10 vertical to 1 horizontal:		
7,280,000 cubic yards, at 80 cents	$5,824,000	

Excavation through higher portion of Culebra cut from mile 32.80 to mile 37.50, 45 feet deep and 200 feet wide at bottom, quantities computed from typical cross section adopted by the Board, but enlarged by widening berm at elevation 245:		
39,650,000 cubic yards, at 80 cents	$31,720,000	
Excavation from mile 37.50 to northerly end of Pedro Miguel locks (mile 39.37), channel 45 feet deep and 300 feet wide, with slopes of 4 vertical to 1 horizontal, in rock:		
6,835,000 cubic yards, at 80 cents	5,468,000	
Total for Culebra cut, 53,765,000 cubic yards, at 80 cents		$43,012,000
Allowance for diversion channels for streams between Obispo and Pedro Miguel		850,000
Excavation for Pedro Miguel locks, mile 39.37 to mile 39.60:		
Earth, 650,000 cubic yards, at 40 cents	$260,000	
Rock, 520,000 cubic yards, at $1.15	598,000	
		858,000
Pedro Miguel locks, exclusive of excavation and approach walls		5,935,000
Approach walls to Pedro Miguel locks		300,000
Back filling and embankment at Pedro Miguel locks, 390,000 cubic yards of borrowed earth, at 50 cents		195,000
Pedro Miguel dam:		
Earth embankment, 1,100,000 cubic yards, at 25 cents	$275,000	
Add for preparatory work and miscellaneous expenses	50,000	
		325,000
Excavation from mile 39.60 to mile 41.47, making channel 45 feet deep and 500 feet wide:		
Earth (dredging) 1,460,000 cubic yards, at 25 cents		365,000
Excavation from mile 41.47 to northerly end of Sosa locks (mile 45.08), making channel 45 feet deep and not less than 1,000 feet wide:		
Earth (dredging), 220,000 cubic yards, at 25 cents		55,000
Excavation for Sosa locks (mile 45.08 to mile 45.49):		
Earth, 480,000 cubic yards, at 40 cents	$192,000	
Rock, 950,000 cubic yards, at $1.50	1,425,000	
		1,617,000
Sosa locks, exclusive of excavation and approach walls		11,000,000
Approach walls for Sosa locks		450,000
Back filling and embankment at Sosa locks, in part rock from excavations and in part borrowed earth:		
950,000 cubic yards, at 50 cents		475,000
Excavation from Sosa locks (mile 45.49) to deep water (mile 49.72), 300 feet wide and 45 feet below mean sea level:		
Earth, 4,760,000 cubic yards, at 15 cents	$714,000	
Rock, 200,000 cubic yards, at $1.50	300,000	
Rock, 370,000 cubic yards, at $2.50	925,000	
		1,939,000
Ancon-Sosa and Ancon-Corozal dams:		
5,980,000 cubic yards, at 25 cents		1,495,000
La Boca dam:		
Embankment, 6,300,000 cubic yards, at 25 cents	$1,575,000	
Shutting off tidal flow at mouth of Rio Grande	100,000	
		1,675,000
Diversion channel and regulating works at dam between Ancon and Sosa hills		275,000
Add for preparation of sites and for extras at the dams at the Pacific end of the canal		150,000
Panama Railroad diversion from Gatun to Bohio (say)	$2,000,000	
Panama Railroad diversion from Bohio to Pedro Miguel	1,300,000	
Panama Railroad diversion from Pedro Miguel to Panama	400,000	
		3,700,000
Movable dams at the Gatun and Pedro Miguel locks for stopping the flow from the summit level in the event of the destruction of the lock gates		2,000,000
Land damages, Gatun and Sosa lakes		300,000
		116,421,000
Add 20 per cent for administration, engineering, and contingencies but not including interest during construction, sanitation, or expenses of Zone government		23,284,200
Total		139,705,200

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